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ABSTRACT

These proceedings contain abstracts of 164 papers in the area of interdisciplinary rehabilitation research, focusing on the theme of "The Promise of Technology." The abstracts are organized into the following sections: "Home and Worksite Modification," "Computers and Microprocessor Systems," "Neuromuscular Electrical Stimulation," "Transportation," "Wheelchairs," "Communication Aids," "Seating and Pressure," "Control Interfaces," "Independent Living Aids," "Functional Assessment," "Aids for Sensory Impaired," "Biofeedback and Therapeutic Equipment," "Biomechanics, Motion Analysis, and Robotics," "Recreational Equipment," "Service Delivery and Vocational Rehabilitation," "Special Session: Orthotics/Prosthetics," and "PVA (Paralyzed Veterans of America) Student Design Competition." The detailed abstracts contain diagrams, charts, graphs, photographs, and references. (JDD)

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Proceedings of the Sixth Annual Conference on Rehabilitation Engineering

San Diego, California
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1983 –
The Promise
of Technology

RESNA
Rehabilitation Engineering Society of North America
An Interdisciplinary Society for the Advancement of Rehabilitation through Technology

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The Promise of Technology

Proceedings of the Sixth Annual Conference on Rehabilitation Engineering

San Diego, California
June 12-16, 1983

Bruce R. Bowman, Sc.D.
Editor

Donald R. McNeal, Ph.D.
Daniel W. Monzingo, J.D.
Conference Co-Chairpersons

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The Rehabilitation Engineering Society of North America (RESNA) is an organization concerned with the exploitation of science and technology in the rehabilitative process. Its membership includes rehabilitation professionals (drawn from all pertinent disciplines), providers, and consumers. A goal of the organization is to promote interaction between these groups so they can better understand and serve the needs of those who can benefit directly from the application of rehabilitation engineering technology.

This volume represents an excellent cross section of the results of rehabilitation research during the past year. Its interdisciplinary character epitomizes the philosophy of RESNA; that is, that rehabilitation engineering is a team approach that requires the skills of many professionals--physicians, engineers, therapists, nurses, to name a few--as well as consumers, without whose input the advancement of rehabilitation technology would be severely curtailed.

This year's theme, The Promise of Technology, was demonstrated not only by the scientific papers that comprise this book but also through instructional courses, advanced topic discussions, luncheon seminars with experts, product demonstrations, student design projects, tours of rehabilitation facilities, and an exhibition.

The editors thank all those who contributed so importantly to this publication.

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Scientific Papers

Keeping with the goals of RESNA, this year's authors of scientific papers cover a diversity of professions reporting on a diversity of topics. A total of 152 papers were accepted covering 16 subject areas. Authors represent 25 states as well as Canada, England, Yugoslavia, Sweden, and Japan.

Much of the success in soliciting the large number and high quality of papers submitted this year was due to efforts of the 15 Session Chairpersons. Each Session Chairperson, an expert in their field, accepted the responsibility of personally encouraging leading colleagues in their area of research to submit papers to RESNA. The Session Chairpersons were responsible for setting up panels of experts to review papers submitted to their session to insure that papers accepted were of high standards of excellence. Each chairperson put a great deal of time, effort and pride into developing their session and offered many valuable suggestions regarding organization of the scientific papers.

I would like to thank the Session Chairpersons for their much-needed contributions. I also would like to thank the Organizing Committee, particularly Conference Co-chairperson Donald McNeal, and the RESNA office for all their valuable assistance, and commend this year's authors for their excellent work and interest in participating in RESNA.

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WORKSITE EVALUATION: AN INTEGRAL COMPONENT OF SUCCESSFUL EMPLOYMENT

GAIL MAGDALENA, O.T.R., NANCY SOMERVILLE, HEIDI MCHUGH PENDLETON, O.T.R.

PROJECT THRESHOLD, RANCHO LOS AMIGOS HOSPITAL

ABSTRACT

Enabling a person with a disability to physically manage job tasks can be instrumental in facilitating and maintaining their employment. The following paper presents one method of performing worksite evaluations using a systematic approach involving the client, the evaluator and as necessary, appropriate allied health professionals. This approach includes a functional evaluation, analysis of all job tasks, assessment of the work environment, research and trial of solutions, and finally a detailed written report. The importance of maintaining communication with the employer is stressed. Various resources for obtaining information on equipment are discussed. Cases illustrating both simple and complex worksite evaluations are described.

INTRODUCTION

A person with a physical disability may encounter obstacles when pursuing or trying to maintain employment. These obstacles can often be eliminated by the individual learning alternative methods of job performance, by restructuring the job or by modifying the worksite. Although many work related problems can be solved independently by the individual with a disability and his employer, in other situations assistance of outside resources may be required. This assistance may be needed in both the exploration phase, when solutions are being sought to work-related problems, and in the implementation phase, when a possible solution is found but assistance is needed in locating a resource for purchase, design, fabrication, and installation.

Today there are community resources available which address the area of worksite evaluation. One such resource is Project Threshold, a service delivery program located in Downey, California. This program offers a variety of services to severely disabled individuals who are no longer receiving rehabilitation. Of the services provided, approximately one-third involve worksite evaluations.

The clients seen in this particular program characteristically are individuals who plan to resume their former jobs following a disability, people unable to return to the demands of their former job but who are seeking an alternate form of employment, or those who have never been employed. The intervention by Project Threshold with these individuals has ranged from simple and inexpensive solutions to the more complex, time consuming, and costly.

PROCESS

One way to approach worksite evaluations is to utilize a systematic process. This process involves considering the functional abilities of the disabled employee, the tasks to be performed, the worksite environment, and the needs and concerns of the employer. For worksite evaluations to be successful all of these factors, which are interdependent, must be evaluated and addressed in a holistic manner.

To devise an appropriate solution which can be quickly and effectively implemented, we involve allied health professionals with varying backgrounds. These professionals can include occupational therapists, physical therapists, rehabilitation engineers, and others with expertise in evaluation and problem solving. One staff member takes responsibility for case management, and additional staff or consultants are added as required by the type of evaluation to be conducted. The client is an integral member of the team and often brings to the evaluation a wealth of creative ideas and valuable input. While the employer may not be an active member of the team, successful implementation of solutions resulting from the worksite evaluation will depend upon his or her cooperation. Often this cooperation is enhanced by communication with the employer early in the process.

The functional assessment is the first step in this process and is pivotal to a successful outcome. While muscle tests or other standard assessments can provide useful information, observation of the client's actual performance in work related tasks is of far more value. Discovering the client's/employee's abilities and limitations in all daily activities, including these work-related tasks, provides a key to developing a master plan for worksite solutions and modifications. It is at this point in the process that the identification of the employee's abilities and limitations may also be a determining factor as to whether therapeutic intervention such as muscle strengthening or other form of conditioning is needed.

With the employee's abilities and limitations in mind, the next step is to analyze the tasks to be performed. All tasks must be identified and the standard method of performance described in detail including physical demands and the commonly used equipment or tools. For fairly standard tasks, a verbal description is often sufficient; however, for highly technical tasks direct observation of another employee performing the task is critical.

Investigation of the worksite environment coincides with the analysis of job tasks. It is important to evaluate not only the accessibility of the primary worksite, but to also consider access to parking, building entrances, restroom, lunch area, and any other areas which the employee may be required to utilize.

At this stage in the process, equipment or techniques can be tried which appear to be possible solutions based on the information gathered from the functional assessment, job task analysis and the evaluation of the work environment. It is helpful to have a stock of equipment available for this purpose. When the appropriate device is unavailable for trial use, similar devices may be substituted, or makeshift solutions can be developed to provide an indication of the feasibility of the desired device. The benefits of this "hands-on" experience are that it helps to ensure that the proposed solution will indeed solve the problem. This trial will also demonstrate to the employer that the employee will be able to perform the required job tasks.

Many employers are unfamiliar with disabilities and the potential of using simple techniques, assistive devices or modifications for problem solving. They may have preconceived ideas of drastic structural modifications which may be disruptive to the work environment and which they may feel will affect quality, productivity and the attitudes of other employees. Therefore, early communication with the employer regarding possible solutions, and his or her actual observation of the trial of these solutions cannot be overestimated in facilitating the disabled person's employment.

The worksite evaluation is not complete, and in fact is of little value, unless the recommendations are outlined in detail in a written report. This report should include a detailed description of any new methods for job performance or training required in these methods, diagrams indicating adjustments in the work area, and specific names of sources and cost of any required equipment. This report should be shared with the appropriate individuals involved such as the employee, the employer, and the referral source. Much of the research which goes into preparing the report is devoted to locating resources which will assist in implementing the solutions. Many of these resources can be found within the community, and include home improvement centers, department stores, hardware stores, office equipment distributors and other businesses specializing in various types of equipment. Catalogues provided by these various companies make researching equipment easier and less time consuming.

Another resource which is available to the public at no cost is Abledata. This service consists of a national computerized databank containing information regarding more than 5,000 commercially available products which may be of use to people with disabilities. These products may be either specially designed items, or standard equipment which have applicability for those with physical limitations. The product data is delivered through information brokers who supply equipment description and costs as well as local sources for obtaining equipment items. To locate the information broker nearest you, contact National Rehabilitation Information Center in Washington, D.C. at 202/635-6090.

When solutions have been devised and assistance is required for implementation or fabrication, the community is often a good place to turn. Carpenters or handymen may fabricate appropriate items such as ramps, special tables or platforms. People familiar with fabrication of equipment can be found by referring to the telephone book, or by contacting community resources such as independent living centers, service organizations, or businesses providing specialized services that could be transferrable to the needs of a person with a disability. Ideas for locating resources may also be obtained by contacting disabled individuals who have been successful in soliciting community assistance. The person requesting these resources must be specific in relating the proposed use and specifications of the equipment needed to ensure an appropriate end result.

APPLICATION

The presentation will illustrate a range of solutions to worksite problems. The following describes two such representative cases. The first case involved a 28 year old woman with a diagnosis of Arthritis. She was employed full-time as an invoice records clerk for a department store, and was experiencing fatigue and joint pain which seemed to increase following her work activities. A worksite evaluation was performed to evaluate her physical picture and explore the tasks required in job performance. During her functional assessment, it was noted that she had use of both her upper and lower extremities, and was able to ambulate without the need for assistive devices. There were, however, noticeable joint changes, and the client complained of pain and fatigue in her upper and lower extremities, back and neck. With these factors in mind, a detailed analysis of the tasks involved in her job was begun.

As an invoice records clerk, much of her job responsibilities included writing, stapling, operation of a calculator and filing. In observing her during the performance of her work tasks, it became evident that the equipment used and her method of job performance placed tremendous stress on the joints of her upper extremities, her neck and her back. The flat horizontal surface of the desk forced her to position her neck in flexion during task performance resulting in fatigue and pain after a short period of time. The stapler, which she was required to use repeatedly, resulted in increased pain in her hand and wrist. In addition to stapling, removing staples was a problem due to her painful joints which limited her strength. It was also noted that retrieving fallen objects was painful due to stress placed on her back and the joints of her lower extremities.

Following the assessment of her worksite environment, which included use of the restroom, possible solutions were tried. The resulting recommendations included an angled portable drawing board, non-slip matting to prevent equipment from rolling off this angled surface, a foot stool to provide better seating position thus decreasing back pain, an electric stapler, and reachers (Figure 1). In addition to these commercially available items, a simple custom modification was made to a staple remover providing her with a comfortable grip.

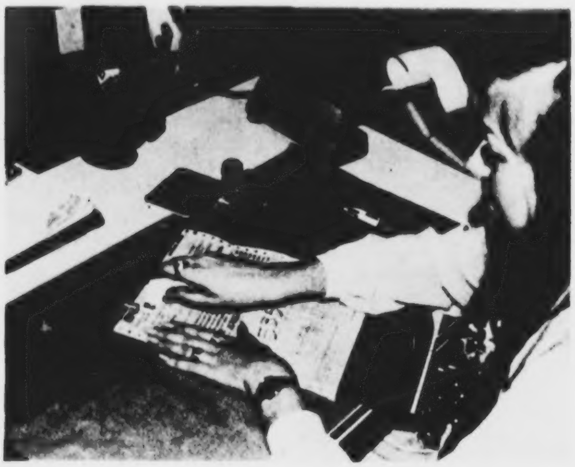


Figure 1 Commercially available devices such as this portable angled drawing board, and a modified staple remover were instrumental in solving this employee's worksite problems.

Another case example involved a woman who had severe physical limitations as a result of polio as a child. This client, who was an accomplished mouthstick user, was being considered for employment as a directory assistance operator for a telephone company. The client was unable to perform the job duties in the traditional manner, so a worksite evaluation was conducted to determine what equipment would be required to enable her to perform the job duties.

The job tasks included using a video monitor and keyboard to access telephone numbers, using a marker (normally hand held) under the desired number to ensure accuracy in relating information to the caller, and accessing a small telephone console to transfer problem calls to the supervisor. Colored flags were used to indicate equipment trouble, need for supervisor assistance and to indicate breaks. In addition, paper and pen were used to note difficult names or unusual spellings. The challenge to Project Threshold was to modify the worksite to allow performance of all tasks by the client using a mouthstick. This was complicated by the client's limited neck range.

In this case, a great deal of time was spent in problem solving and researching possible solutions. This resulted in involvement of the telephone company and Project Threshold contributing to a customized worksite. The telephone company raised the height of the work surface, installed a ramp at the building entrance and widened a bathroom door. Project Threshold provided a mouthstick with interchangeable tips, a holder for the mouthstick, an angled platform for placement of the keyboard, a sliding marker attached to the monitor, and a system for raising the colored flags. In addition, racks for placement of government telephone listings were provided. Involvement of the employer in this case was critical to successful employment of the client.

SUMMARY

In summary, worksite evaluations have been identified as an important component for facilitating and maintaining employment for persons with physical disabilities. A method of conducting these evaluations was discussed. The major focus of the presentation will be a description of the steps involved in this evaluation process. In addition, sample solutions to actual worksite problems will be presented. These examples will demonstrate the importance of using a systematic assessment approach involving the employee, the worksite evaluator and the employer.

This project was supported by the California State Department of Rehabilitation, contract number 9046.

Project Threshold, Rancho Los Amigos Hospital,
7601 East Imperial Highway - 500 Hut, Downey,
California 90242

1.2

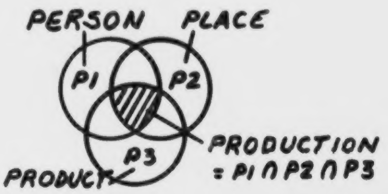
REHABILITATION ENGINEERING IN MANUFACTURING - MATCHING PERSON, PLACE AND PRODUCT

James A. Dewees

Center Industries Corporation
Cerebral Palsy Research Foundation of Kansas

ABSTRACT

All manufacturing engineers regardless of their affiliation with rehabilitation face the challenge of matching the capabilities of the production personnel with the design and layout of the facilities in order to produce a viable product. Mutual compatibility of the person; the place, which includes all machines, materials, assistive devices etc. occupying the work space; and the end product and its components is essential to successful manufacturing. This match up of person, place and product is even more important when the person has significant limitations. Hence, for this study, "production" is defined as the result of the intersection of its three basic parts; person (P1), place (P2) and product (P3) as the following Venn diagram simply illustrates.



Other Venn diagrams are shown in the MATERIALS AND METHODS section of this report to illustrate degrees of compatibility between the basic production components. Some of the diagrams depict the match-up of P1, P2 and P3 when P1 possesses certain limitations.

INTRODUCTION

In most mainstream industry an optimal match-up of person, place and product means that the unskilled, inexperienced, physically and mentally impaired persons get screened out. This type selection process is counter to vocational rehabilitation creating a real gap between the "demand" to employ the handicapped and the short "supply" of manufacturers equipped (or motivated) to do so.

This study focuses on some of the work site modification challenges at Center Industries Corporation (CIC), a competitive manufacturing plant located in southwest Wichita, Kansas. The work force at CIC is composed predominantly of physically disabled persons.

CIC is used by the Rehabilitation Engineering Center of the Cerebral Palsy Research Foundation of Kansas as a "real world" research laboratory and is often demonstrated as a working model. It is also available to the College of Engineering at Wichita State University for studying the employability of physically handicapped persons.

BACKGROUND

CIC is a 52,000 square feet, non-subsidized, not-for-profit manufacturing facility employing approximately 65 persons, the majority of whom, as mentioned, are physically handicapped. Annual sales during 1982 totalled nearly $1.6 million to 30 major customers and for the past three years, revenue has been derived totally from the sale of manufactured products.

CIC was developed following attempts by its founder to interest local mainstream industry in hiring physically handicapped persons of work force age. Much had been done for these people during the first one-third of their lives but the outlook for productive occupation thereafter was bleak. Unsuccessful efforts to find gainful employment for persons not meeting the skill and capability standards set by competitive employers (as discussed in the INTRODUCTION) inspired the CIC concept, which has since become a reality. CIC began production in June 1975 through grants and loans from the Kansas legislature, Vocational Rehabilitation (SRS) and the SBA.

Statistics indicate there are 30.5 million people of work force age (18 to 64) who possess some form of functional impairment including limitations of physical motion, mobility, hearing, speech and vision plus mental or emotional difficulties. Those persons with motion or mobility limitatioins impeding their ability to perform productive work total approximately 17 million. Of the 17 million, there are about 8 million who are categorized as "severely disabled" in that it is not possible for them to be employed without engineering modification to the work site and without full-time aide and attendant care (1). Unfortunately, mainstream industry "generally" is not yet prepared economically, technologically, nor philosophically to turn disabled persons into productive tax-paying employees. This is manifested in the fact that only about 10% of the 410,000 clients served annually by rehabilitation workshops get placed into mainstream industry (2). Considering these figures, society must be made aware of how the industrial work site might be modified to accommodate or circumvent worker disabilities. Establishing some of that awareness is an aim of this paper.

METHODS AND MATERIALS

Insuring compatibility between the person (P1), the place (P2) and the product (P3) in order that efficient production can take place requires that P1, P2 and P3 be looked at both separately and collectively. The successful combination might include an adaptive device custom built for the person, a modification to tooling or to the building, a change in product specifications or manufacturing processes, or alterations to any combination of the three. There is often a tendencyfor an engineer in manufacturing to focus exclusively on P1, P2 and P3 and overlook the most efficient and workable combination. A rehabilitation engineer in manufacturing usually will find it necessary to consider all three, since P1's radius of capabilities, versatility and/or tolerence will be limited and must be accommodated for through adjustments to P2 and/or P3.

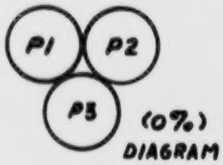


DIAGRAM A

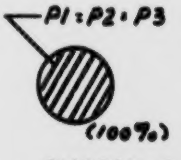


DIAGRAM B

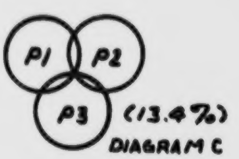


DIAGRAM C

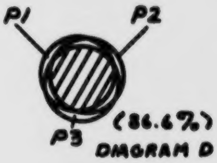


DIAGRAM D

Diagram A represents "zero" compatibility. (P1), (P2) and (P3) share no common elements, therefore it is assumed that production as defined for this study cannot take place at this level. Diagram B represents "perfect" (100%) compatibility, that is, all elements of each component are indistiquishable. Needless to say, 100% compatibility is not achievable in the real world. Diagrams C and D represent the more realistic minimum acceptable (13.4%) and maximum achievable (86.6%) compatibility levels respectively. Calculations of the 13.4% and 86.6% are shown in Diagram E.

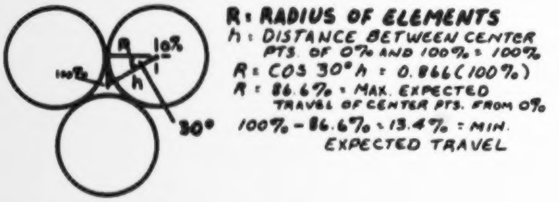

R
10%
100%
h
1
30°
R: RADIUS OF ELEMENTS
h: DISTANCE BETWEEN CENTER PTS. OF 0% AND 100% = 100%
R = COS 30° h = 0.866(100%)
R = 86.6% = MAX. EXPECTED TRAVEL OF CENTER PTS. FROM 0%
100% - 86.6% = 13.4% = MIN. EXPECTED TRAVEL

DIAGRAM E

Diagram F illustrates "normal" (50%) compatibility, as shown in the diagram on page 1. The center points of P1, P2 and P3 lie half way between "zero" and "perfect" compatibility and are also at the midpoint between 13.4% and 86.6%. This diagram depicts the goal of rehabilitation engineering in manufacturing, that is, to arrive at a "normal" area of intersection of P1, P2 and P3 through work site modification. It may be assumed for the purpose of quantifying compatibility levels that the "normal" workable range is between 13.4% and 86.6%.

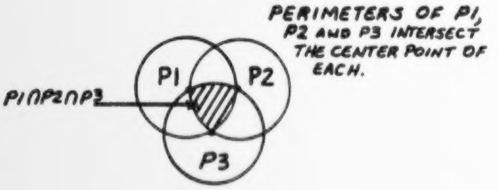

PERIMETERS OF P1, P2 AND P3 INTERSECT THE CENTER POINT OF EACH.
P1∩P2∩P3
P1
P2
P3

DIAGRAM F

The handicapping conditions of the disabled employees at CIC are grouped and ranged as follows:

- Cerebral Palsy; severe, moderate and mild
- Brain Trauma resulting from accidents as young adults, moderate to severe
- Post-Polio, moderate to severe
- Brain Damage resulting from surgical procedure error causing blindness and mobility impairment, moderate to severe
- Double Amputee (legs) from an autombile accident
- Spinal Cord Injury from a motorcycle accident, paraplegic
- Spina Bifida, non-ambulatory
- Arthritic Condition, severe, non-ambulatory
- Loss of use of One Arm from a motorcycle accident
- Single Amputee (leg), Viet Nam veteran
- Hearing Impaired, moderate to severe
- Mentally Retarded, mild to moderate
- Emotionally Impaired, mild to moderate
- Single Thumb Amputee, industrial accident
- Neurological and/or Orthopedically affected, very mild to mild

Diagrams 1, 2, 3 and 4 show how persons with disabilities might be represented using Venn diagrams. Keep in mind the "normal" compatibility ranges shown in Diagrams C, D and F and visualize how P2 and P3 might be modified to offset P1's limitations.

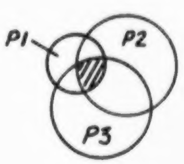


DIAGRAM 1

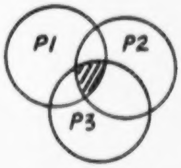


DIAGRAM 2

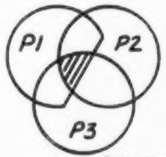


DIAGRAM 3

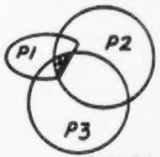


DIAGRAM 4

In Diagram 1, P1 is shown as having a smaller than "normal" radius of capabilities. This might represent an individual with physical limitations causing generally impaired versatility and speed.

Diagram 2 is drawn with P1 farther away from P2 and P3 than "normal" meaning that there may be communication, transportation or general mobility problems making it difficult for the person to "get to" the work place and/or to understand the requirements for production.

Diagram 3 shows P1 with a missing or non-functional part resulting from amputation, spinal cord injury or nerve damage. Note that a rotation (change of required motions) of P1 would allow utilization of available capabilities for "normal" compatibility.

Diagram 4 shows an irregularly shaped P1 representing an individual with multiple handicaps. P1 possesses most if not all the impairments shown in Diagrams 1, 2 and 3 and is the most difficult to employ.

RESULTS

The preceding diagrams suggest a way to look objectively at the production process as a combination of the compatible elements of person, place and product. If the area of each circle representing P1, P2 and P3 is a measure of the workable elements of each, then the area of the intersection could represent the degree of compatibility between them.

Below are brief descriptions of four (4) actual incompatibility situations at CIC plus the work site modifications used to overcome or circumvent them.

1. Situation CIC has a bus that transports 20 employees to and from work daily. Unloading and loading the bus in the mornings and evenings required from 20 to 30 minutes. During inclement weather the difficulties were multiplied, plus maintenance costs on the hydraulic lift were high.
   Solution A 32" high x 40" wide x 32' long ramp is built parallel to a wall inside the building. Unloading and loading now takes 5 to 8 minutes and lift maintenance is reduced.
2. Situation Terry has cerebral palsy, reclines in his wheelchair almost horizontally, and has the use of only his thumb and forefinger of his right hand. He desired employment as a production machine operator.

Solution Terry operates a machine which crimps, or reforms one end of round 10" long pieces of steel tubing to a triangular shape. Terry grasps the 10" tube with two fingers and places it into a V-channel then pulls an air valve handle with one finger which inserts the tube into the machine. A series of microswitches causes three hydraulic cylinders to close, retract and then eject the tube, at the same time causing another tube to be dispensed automatically within Terry's reach. Terry drops the crimped tube into a hopper and repeats the cycle.

3. Situation Mike lost the use of his right arm in a motorcycle accident. He desired to operate an N.C. Lathe which requried the use of two hands; one to press a switch which opens and closes the jaws of the chuck and the other hand to insert and remove the machined part. Solution A head-operated device using two microswitches wired in parallel with the original switch allows Mike to open or close the chuck by leaning his head left or right.
4. Situation Larry suffered brain trauma in an automobile accident at age 19, leaving him generally physically impaired. All his physical functioning, communicating and reasoning abilities were "slowed" significantly, however, he still retains adequate hand strength. Larry's goal was to operate an automatic drill press. Solution The product that is drilled by Larry's machine is a 4½ lb. ductile iron casting. Each casting is gravity fed correctly oriented to Larry's work station by a dispenser that is loaded as required by a less severely impaired co-worker. The drill press is positioned for Larry's wheelchair, work height and reach. Larry grasps the casting, places it into a holding fixture, pulls a lever to clamp the casting and presses another switch to start the drill (speed and feed are preset and automatic). Once the drill cycle is complete, Larry pulls a lever to release the casting from the holding fixture, places the casting into a box and repeats the cycle.

In addition to the aforementioned direct labor employees, several disabled persons occupy management or indirect labor positions, such as operator-receptionist, office manager, clerk typist and production supervisors.

Other general adaptations within CIC that allow employee mobility, accessibility, safety, etc. are:

- All aisleways are at least 6½ ft. wide and restroom facilities are built to accomodate all employees.
- A full-time aide/attendant is on staff. This person also works as security guard, bus driver, first-aid attendant and vending machine stock person.
- A wheelchair height "gang" type hand-wash station is provided with special floor pedals which can be operated by rolling a wheelchair upon them.
- All stairways have hand rails on both sides for use by one-handed persons.
- Exposed corners of work tables, equipment, etc. are padded or rounded and guardrails are installed in front of accessible large windows for the safety of those workers who are somewhat unstable in transit.
- Air operated drill presses and other equipment have special safety interlocks which shut off the air supply when the operator's hands, etc. are near hazardous areas.
- There are persons available to provide emergency wheelchair maintenance or "first-aid". Extra wheelchairs, manual and electric, and some replacement parts are on hand. This service is important since a non-ambulatory person's wheelchair is a means of basic mobility rather than just a general form of transportation.

DISCUSSION

Above and beyond the specific work site modifications, the following general items might be considered as possible "door openers" for the disabled into mainstream competitive industry. The items are somewhat broad, idealistic comments unrelated to specific engineering tasks, but before rehabilitation engineers can modify competitive work sites to a significant degree there must be a significant number of work sites to modify.

- An economic study could compare the cost-benefits of current corporate dollar contributions versus providing employment.
- Corporate industries could expand the concept of hiring rehabilitation specialists into training management, supervision and engineering in rehabilitation techniques.
- Rehabilitation engineering in manufacturing, in some cases, may simply mean developing an organized "shop aide" support service. (This was observed by an individual employed by one of CIC's major customers during a tour of CIC.)
- Handicapped persons could be withdrawn only gradually from government support as they become gainfully employed. Government funding could be reduced as wages and employee productivity increase. Also, hiring of the disabled could be done by small departments within competitive industry and then expanded as capabilities grow.

CONCLUSIONS

If this paper starts the reader thinking in terms of "production being the integration of person, place and product" and that rehabilitation engineering in manufacturing must address the mutual compatibility of person, place and product, the objective has been understood. If there is at least one work shop or competitive industry who puts to use one concept presented herein the objective has been met.

In closing, it should be noted that during the past 3 years, the greatest obstacle to successfully employing disabled persons at CIC has not been problems associated with physical disabilities, rather the greatest obstacle has been the lack of long term manufacturing contracts. In other words, production has been hampered primarily by product, not person, limitations.

REFERENCE

1. U.S. Department of Health and Human Services,
WORK DISABILITY IN THE UNITED STATES,
SSA Publication 13-11978 and

U.S. Department of Health and Human Services,
PREVALENCE OF SELECTIVE IMPAIRMENTS,
DHHS Publication 81-1562

2. Sale, R.T., EMPLOYMENT, THE WHITE HOUSE CONFERENCE ON HANDICAPPED INDIVIDUALS. Awareness Papers, Washington, D.C., May 23-27. 1977, PP. 205-216

ACKNOWLEDGEMENT

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FIVE SIMPLE WORKPLACE TOOLS

Leonard L. Anderson, M.S.E.M.
Cerebral Palsy Research Foundation of Kansas, Inc.
Rehabiliatation Engineering Center

ABSTRACT

The Rehabiliatation Engineering Center in Wichita, Kansas, has, as its emphasis, research in the area of placing severely physically disabled persons in the workplace. The R.E.C. is under the sponsorship of the Cerebral Palsy Research Foundation of Kansas, Inc., and is federally funded thru the National Institute of Handicapped Research.

INTRODUCTION

Members of the Rehabilitation Engineering Center have developed a number of tools specifically designed for use by workers who have "unsure" or shaky hands, have limited range of motion, or perhaps have only one functioning hand. Five such devices which have been found to be very successful are presented here.

DEVICES

Adjustable Work Carrel

It has been determined that it is helpful, at times, for the disabled worker to have a carrel in which to work. The carrel shown in Figure 1 has been designed and is in use at several different work stations. The movable work surface has adjustments both in height and tilt. The parts bin holder and parts bins provide for readily accessible small parts to be used in assembly, inspection, or whatever. The cutout in the work surface provides for elbow support and better working posture when needed.

O-Ring Installation Tool

In most cases where it is necessary to install a rubber o-ring seal externally on a shaft it is necessary to expand the diameter of the o-ring. It is difficult to expand the diameter uniformly without using some sort of tool.

Wood dowel was used to make a cylindrical-shaped tool which has, at one end, a diameter slightly less than the free inside diameter of the o-ring to be installed. In the center of the length of the tool is a transition section to a diameter which is slightly larger that the shaft over which the o-ring is to be placed. See Figure 2.

If the portion of the tool which has the smaller diameter is sufficiently long several parts to be installed may be stored to facilitate speed in an assembly-line process.

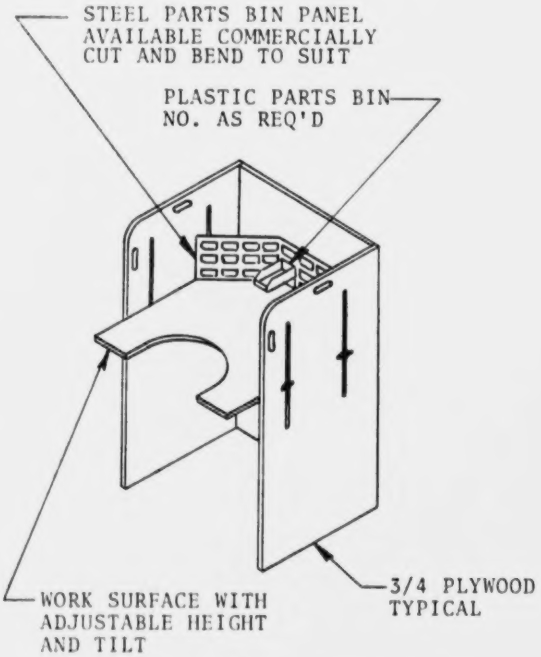

STEEL PARTS BIN PANEL
AVAILABLE COMMERCIALLY
CUT AND BEND TO SUIT
PLASTIC PARTS BIN
NO. AS REQ'D
WORK SURFACE WITH
ADJUSTABLE HEIGHT
AND TILT
3/4 PLYWOOD
TYPICAL

FIGURE 1: ADJUSTABLE WORK CARREL

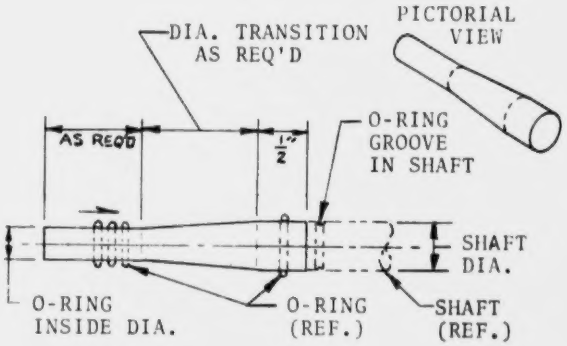

PICTORIAL
VIEW
DIA. TRANSITION
AS REQ'D
AS REQD
1"
2
O-RING
GROOVE
IN SHAFT
SHAFT
DIA.
O-RING
INSIDE DIA.
O-RING
(REF.)
SHAFT
(REF.)

FIGURE 2: O-RING INSTL TOOL

Sticky-Back Lable Dispenser

Sticky-back lables are sometimes difficult to remove from their waxed paper backing. The tool shown in Figure 3 not only provides for the easy removal of the lables from their backing, but allows for one-hand accomplishment of the task.

As the backing paper with the sticker attached is bent over a sharp corner the backing paper will follow the bend, but the sticker will peel off and continue in the plane prior to the bend.

As the figure shows, tools can be made to accommodate backing paper of differing widths, and thus, stickers of varying sizes. It is quite easy to verify if a similar device would satisfy removal of a particular sticker by simply drawing the backing paper accross any sharp corner to see if the sticker will, indeed, peel off in the process.

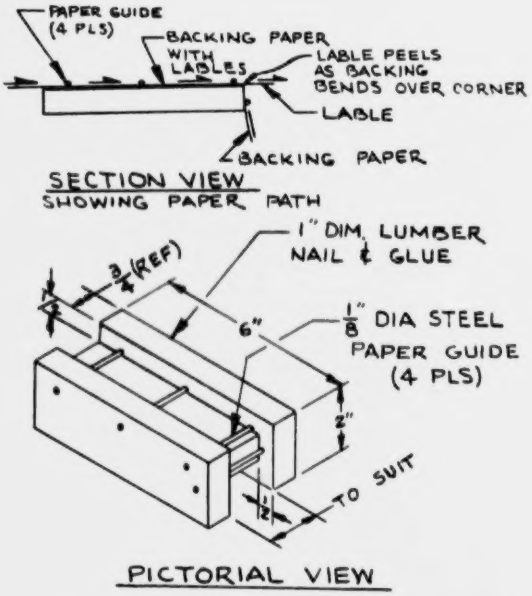

PAPER GUIDE (4 PLS)
BACKING PAPER WITH LABLES
LABLE PEELS AS BACKING BENDS OVER CORNER
LABLE
BACKING PAPER
SECTION VIEW
SHOWING PAPER PATH
1" DIM. LUMBER NAIL & GLUE
3/4 (REF)
6"
1/8" DIA STEEL PAPER GUIDE (4 PLS)
2"
1/2
TO SUIT
PICTORIAL VIEW

FIGURE 3: STICKY-BACK LABLE DISPENSER

Cutting Tool For Stranded Nylon Rope

Stranded nylon rope is difficult to cut with a knife as it tends to "roll" under the blade. Also, when cut with a sharp blade, the ends of the rope tend to fray and the rope comes unraveled in the process. It is known that if the free ends of the rope are heated sufficiently to melt the nylon (or plastic), the rope strands will weld together preventing the fraying.

The tool that has been developed not only cuts the rope cleanly, but, the ends of the rope are sealed in the cutting process. See Figure 4.

A soldering iron which develops 80 watts is the main element of the tool. The soldering tip of the iron was replaced with a .020 inches thick piece of copper sheet. As the iron heats, so does the copper sheet. The hot copper sheet then melts its way through the rope cutting and sealing as it goes.

As shown in the figure the iron can be mounted in a fixture which tends to guide the action should a worker with unsure hands desire to use it.

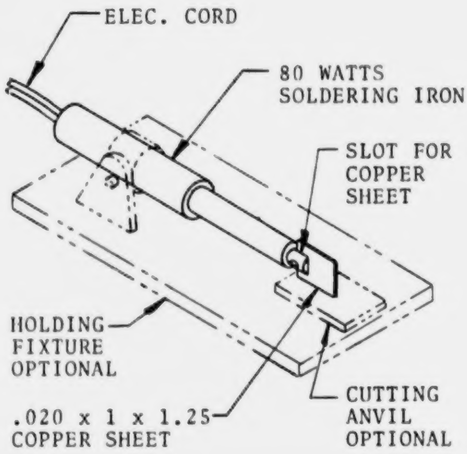

ELEC. CORD
80 WATTS SOLDERING IRON
SLOT FOR COPPER SHEET
HOLDING FIXTURE OPTIONAL
.020 x 1 x 1.25 COPPER SHEET
CUTTING ANVIL OPTIONAL

FIGURE 4: CUTTING TOOL FOR STRANDED NYLON ROPE

Tool For Inspecting Length of Small Parts

The use of a micrometer or other technical measuring instrument is difficult to learn, at best, and is particularly difficult to manipulate for workers who have unsteady hands, or are limited to the use of only one hand. This tool provides for a means to inspect small parts for size when fine tolerances are required. See Figure 5.

The particular application for which this tool was designed was to check the length of small cylindrically-shaped rubber spacers that were approximately 3/8" diameter and 1 1/2" long. These parts are cut to length using a guillotine-type cutting tool and a close tolerance is required on the length because they are used in a tight-fitting location on aircraft. Quality control inspection is required by the buyer.

The individual part to be inspected is placed on the spring-supported shelf when the shelf is in its uppermost position. The worker then moves the shelf downward until the part is "caught" by the tapering sides of gage area of the tool. If the part lies within the "acceptable" range of the tool it is a "good" part. If not, it is rejected.

This tool has been found to be most effective on the job. Workers who have cerebral palsy and have very "shaky" hands have been able to do the required inspection. One-handed workers also perform the required task with little or no difficulty.

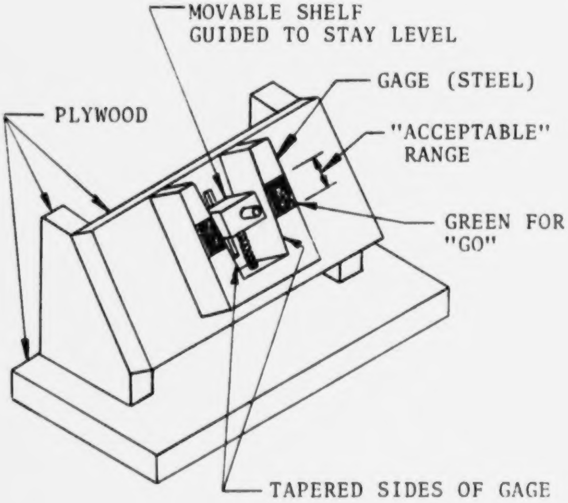

MOVABLE SHELF GUIDED TO STAY LEVEL
GAGE (STEEL)
PLYWOOD
"ACCEPTABLE" RANGE
GREEN FOR "GO"
TAPERED SIDES OF GAGE

FIGURE 5: TOOL FOR INSPECTING LENGTH OF SMALL PARTS

DISCUSSION

All of the tools mentioned herein have proven success records. Workers who have severe physical disabilities as well as ones who are mentally retarded have benefitted from their use.

ACKNOWLEDGEMENT

The auther wishes to acknowledge the National Institute of Handicapped Research and the Rehabilitation Engineering Center for their support in the development of these devices.

Leonard L. Anderson
Director of Engineering
Cerebral Palsy Research Foundation
2021 N. Old Manor
Wichita, Kansas 67208
(316) 688-1888

1.4

ASSESSING THE PHYSICALLY HANDICAPPED FOR INFORMATION PROCESSING EMPLOYMENT

Roy W. Schubert, John Schweitzer, Paul N. Hale, Jr., and Stan Cronk

Department of Biomedical Engineering, Louisiana Tech University

ABSTRACT

This assessment procedure augments the Available Motions Inventory (AMI) work capabilities package by addressing the needs of the more severely physically impaired who may be limited to keyboard-oriented tasks (i.e., spinal-cord injured, MD/CP). A microprocessor-based system to assess gross motor, fine motor, and cognitive skills was developed. This system features computer-displayed stimilus and recording of responses as well as analysis of scores and concise presentation of data. Additionally, observations of the client's performance by a trained multidisiplinary team are simulataneously logged onto a floppy disk for reporting purposes. The use of this new assessment procedure is demonstrated by its application to measure a post-polio victim's capabilities. It was determined that additional money should be invested in developing a computer-based home-site work station. A multi-tasking computer operating system was designed and implemented on a 6502-based microcomputer. This system included a complete accounting software package as well as an environmental control software/hardware package.

INTRODUCTION

In 1978, the Department of Biomedical Engineering at Louisiana Tech University and the Division of Vocational Rehabilitational Services of the State of Louisiana established the Rehabilitation Engineering Research, Development, and Training Center (RERDTC) at La. Tech. The center is housed in the Biomedical Engineering Building and provides the following services to the handicapped: work capabilities assessment, independent living skills assessment, information retrieval system (ARIAD), independent living laboratory, design/modification of assistive devices, residential program and driver education and training program. The goal is to provide an engineering approach to assessment and design for the individual needs of the disabled people in Louisiana.

The work capabilities assessment was developed to assist the severely handicapped individual and complements other assessment and evaluation services available in the state. The two-day assessment quantifies the client's physical abilities and results in the development of a work capability profile of the client. After screening for visual and auditory problems, the Available Motions Inventory (AMI) developed by United Cerebral Palsy of Kansas and Wichita State University (1) is used to collect information on the client's strength, use of dials and switches, use of controllers, eye/hand coordination, two-hand coordination, and reach (vertical and horizontal). This profile can then be used by the client and vocational rehabilitation counselors to locate suitable jobs; and where necessary, modify those jobs. However, a gap existed between procedures for the moderate and severly disabled clients. For example, spinal cord injured people often cannot use their upper limbs at all in the job-task performance.

For the client who is more likely to be trained to handle information versus material in the work place, the Biomedical Engineerng team developed KEYBOARD ASSESSMENT. This assessment has been used on a population with a broad age and physical ability range, which includes potential workers, college students, physically and mentally handicapped children, and handicapped data processing candidates and graduates (2)

KEYBOARD ASSESSMENT was designed as a complement to the AMI-type measurements. It generates information helpful for the most severely disabled clients who are likely to have the cognitive ability to handle information-intensive jobs (such as word-processing, accounting, etc.). Job sites can be analyzed where work is done from a seated position (ie, a wheelchair-work station). Figure 1 shows the relationship of Keyboard Assessment to other rehabilitation assessments.

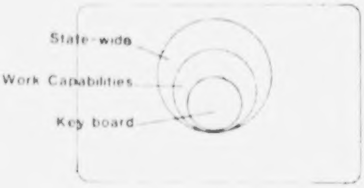


Figure 1. Assessment Population

MATERIALS AND METHODS

Baker and Cook(3) divide the interface assessment into three phases: control site selection, interface selection, and comparative testing of a set of control site and interface combinations. Client records and discussions with the client's psychologist, physical, speech or occupational therapist determine the two most probable "control sites". Procedures were devised to measure the communication rate of these sites by assessing for orthopedic, gross and fine motor skills. These tests, requiring judgements following preception of a screen stimulus, provide a first approximation of cognitive assessment.

The assessment of the client's physical and psycomotor capability to interact with a microcomputer system consisted of three phases: REACTION TIMER, KEYTEST, and TYPETEST. A Commodore PET 2001-32 microcomputer was interfaced with several keyboards and switching arrays which simulated potential input devices for commercially available microcomputers. The PET 2001 computer is programmed to execute, monitor and store (floppy disk) the test/data sequence described below. This sequence includes presentation of instructions, randomized stimulus presentation, and measurement of the client responses (reaction time, movement time, and key hold time.) The computer also statistically analyzes the data and presents the results on the computer screen and/or printer. All times are recorded with an accuracy of 1/60 of a second.

REACTION TIMER: This test uses three large "paddle-type" switches mounted in a row over the computer's keyboard. The client is asked to depress a key until a signal, randomized with respect to time, appears on the center of the computer screen. At this event he is instructed to move his hand or assistive device (such as head pointer) as quickly as possible to the other switch. Five trials are averaged for Center-Right, Center-Left, Left-Right, and Right-Left movements. Both reaction times (time to remove hand from first switch) and movement times (time to depress second switch) are recorded for each trial.

KEYTEST: This series of measurements represents a fine-motor skill test and stimulus discrimination assessment (eye/brain and hand/eye). The client is presented, at random times, ten random letters at the center of the computer screen. The response required is the selection of a matching letter from the computer's keyboard (with 3/4 inch center spacing). The clients are instructed to work as fast as possible. This test also uses a smaller keyboard (1/2 inch center spacing) which is mounted at the "most accessible" position for each client. The keyboard size sequence is randomized among clients. Fingerguards for both keyboards are available.

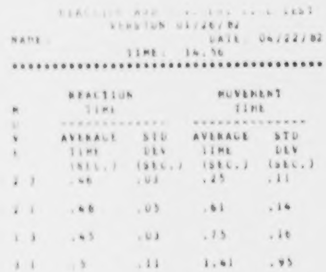
TYPETEST: This test involves typing a complete sentence which has been presented on the screen. Responses are recorded using both small and large keyboards (order randomized among clients). The data display for this test includes a scatter diagram of the time between keys

PROFESSIONAL OBSERVATIONS: A second set of data is collected using an adjacent microcomputer as a word processor. Observations regarding the client's posture, physical condition, medical profile, previous assessment, test scores (such as IQ), strategies for hitting keys, and relevent comments from the client and the multidisiplinary assessment personnel are also entered. The whole record is then stored on floppy disk.

RESULTS

Figure 2 is a printed output of reaction time and movement time due to a visual stimuli. MOVES describes the movement measured with the first number representing the start switch and the second number representing the stop switch. Switch one is on the extreme left, and switch three is on the extreme right.

Figure 3 is the data display from KEYTEST. ENTRY refers to the letter, randomly chosen from the center row of a "QWERTY" keyboard. Note that usually the first key depressed is also the correct key. If this is not the case then the entry shows the actual key sequence used to hit the correct key (the last letter in the entry column). Note that keys below and above "Q" were pushed before the correct key. It is also possible to detect vision difficulties using this test.



```
          [illegible]
          VERSION 01/26/82
NAME:                      DATE: 04/22/82
               TIME: 14.56
****************************************

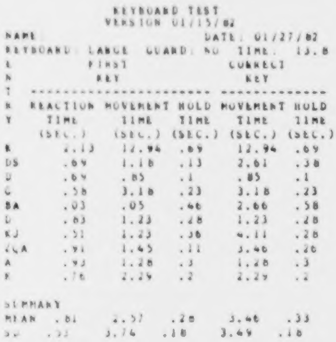
       REACTION          MOVEMENT
M        TIME              TIME
O    --------------  --------------
V    AVERAGE   STD   AVERAGE   STD
E     TIME     DEV    TIME     DEV
S    (SEC.)  (SEC.)  (SEC.)  (SEC.)
2 3    .46      .03     .25     .11

2 1    .46      .05     .61     .14

1 3    .45      .03     .75     .16

3 1    .5       .11    1.61     .95
```

Figure 2. REACTION TIMER results.

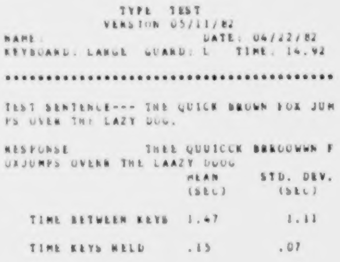


```
           KEYBOARD TEST
          VERSION 01/15/82
NAME:                     DATE: 01/27/82
KEYBOARD: LARGE  GUARD: NO  TIME:  13.8
E         FIRST                CORRECT
N          KEY                   KEY
T  ---------------------- ------------
R  REACTION MOVEMENT HOLD MOVEMENT HOLD
Y    TIME     TIME   TIME   TIME   TIME
    (SEC.)   (SEC.) (SEC.) (SEC.) (SEC.)
K      2.13    12.94   .69   12.94   .69
DS      .69     1.18   .13    2.61   .38
D       .69      .85   .1      .85   .1
G       .58     3.18   .23    3.18   .23
SA      .03      .05   .46    2.66   .58
D       .83     1.23   .28    1.23   .28
KJ      .51     1.23   .38    4.11   .28
ZQA     .91     1.45   .11    3.46   .26
A       .93     1.28   .3     1.28   .3
F       .76     2.29   .2     2.29   .2

SUMMARY
MEAN  .81    2.57   .28    3.46   .33
SD  .53    3.74   .18    3.49   .18
```

Figure 3. KEYTEST results.

Figures 4 and 5 are the results of TYPETEST. The scatter diagram is presented because the mean and standard deviation are not an adequate description of the data, particularly for inexperienced typists. Both the test and response sentences are displayed. Figures 4 and 5 are for different clients. The key hold time can be verified by KEYTEST. TYPETEST is also able to detect multiple entries due to key bounce which shows up as repeated entries (Figure 4).



```
            TYPE  TEST
          VERSION 05/11/82
NAME:                     DATE: 04/22/82
KEYBOARD: LARGE  GUARD: L   TIME: 14.92

****************************************

TEST SENTENCE--- THE QUICK BROWN FOX JUM
PS OVER THE LAZY DOG.

RESPONSE           THEE QUUICCK BBROOWWN F
OXJUMPS OVERR THE LAAZY DOOG
                          MEAN      STD. DEV.
                          (SEC)       (SEC)

    TIME BETWEEN KEYS  1.47          1.11

    TIME KEYS HELD      .15          .07
```

Figure 4. TYPETEST results.

The system cost is minimal as the computer, disk drive, and printer are commercially available. The small keyboard and switches are readily available and are easily connected to the interface connectors. The program is written in Commodore Basic 3.0 and makes no use of machine language.

Figure 5 and Table I present KEYTEST and TYPETEST data from a post polio client and from a somewhat similar able-bodied population.

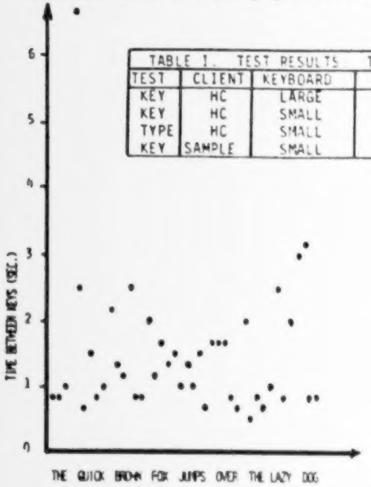


TABLE I. TEST RESULTS TIME BETWEEN KEYS (sec.)

TEST	CLIENT	KEYBOARD	GUARD	MEAN	STD. DEV.
KEY	HC	LARGE	NO	1.62	0.42
KEY	HC	SMALL	NO	1.39	0.34
TYPE	HC	SMALL	NO	1.38	1.01
KEY	SAMPLE	SMALL	NO	1.46	0.39

Figure 5. TYPETEST scatter diagram.

DISCUSSION

KEYBOARD ASSESSMENT has proven to be a useful data collection instrument which is time-efficient, economical, portable, and should be easy to duplicate by others. The reliability of hardware and software have subsequently been demonstated by remote site collection of data on over 80 clients. An assessment can be completed in about 20 minutes.

KEYBOARD ASSESSMENT should be used as a complete package rather than as individual tests. Designed to collect data in a building block fashion, each of the three tests provide specific information which assist the designer in making decisions. REACTION TIMER differentiates physical movement from search time. KEYTEST distinguishes between key-hold time, reaction time, and movement. TYPETEST is the only series of data which provide the designer with key bounce, or multiple-hit keys, information to be used in software modification such that the computer will refuse to process multiple inputs. Results from **KEYBOARD ASSESSMENT** data and PROFESSIONAL OBSERVATIONS are helpful in deciding if the movement time is a true physical movement time or keyboard search time. The measurement of key hold time is a factor not previously reported, to our knowledge. It has been found that this is a neccessity for handicapped individuals that may hold a key long enough to activate an auto-repeat function on standard computers.

The overall assessment referral system was useful in screening the client for this design project. This client is a certified CPA and had a work plan to keep accounts for several local businesses. **KEYBOARD ASSESSMENT** was useful in determining the cost effectiveness of acquiring a computer system for this client. It also was functional in providing a system's analysis for the home-job site scenario. The data was helpful in software aquisition and keyboard modification. The polio client, being a quadriplegic, needed software/hardware beyond an accounting package. Total communication and environmental control using input by mouthstick was needed. Consequently a software patch to the computer's operating system allowed for multitasking (4) between the ADAPTER system (5,6), and comercially available accounting software. As an example, this total package allows the client to respond to incoming phone messages without "losing" the accounting program, and simultaneously use the phone and enter financial data into the computer with a simple two keystroke sequence. Home security can also be implemented.

An exciting result is that muscular dystrophy clients and a large number of cerebral palsy clients demonstrate enhanced performance and display decreased frustration with the small (1/2 inch center spacing) keyboard, as judged by the statistical data and client comments. PROFESSIONAL OBSERVATIONS explained the finding by noting that the small keyboard required one location for hand bracing/support while the larger keyboard required the client to "walk" their hand in a time consuming "crab-like" fashion. The single bracing allowes for more controlled motion. Consequently the authors believe that consideration for a smaller, rather than a larger, keyboard be made for this population. Judging from the availability of very large keyboards, this recomendation appears to be against the current trend and independent verification of our observation is welcomed.

REFERENCES

1. Malzahn,D., and R. Kapur, "An Ability Evaluation System for Persons with Physical Disabilities, 24th. Human Factors Conference, Los Angeles, CA., 1980.

2. Schubert, Roy W., Personal Observation, 1983.

3. Baker, M.R., and A.M. Cook, "A Systematic Approach to Evaluating Physical Ability for Control of Assistive Devices", 4th. Annual Conf. Rehab. Eng., Washington, DC, p.287-289, 1981.

4. Schubert, Roy W., W.W. Moore and Stanley R. Cronk, "Towards Employment of the severly Handicapped", Biomedical Engineering I, Recent Developments, Pergamon Press, p.44-47, 1982.

5. Cronk, S., and R.W. Schubert, "A General Purpose Interface (GPI) for Independent Living", 33rd. ACEMB, Washington, DC, p.209, 1980.

6. Cronk, S, and Roy W. Schubert, "An adaptive computer-aided independant living system for severly handicapped", Biomedical Engineering, Recent Developments, Pergamon Press, p.337-340, 1982.

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Roy W. Schubert
Louisiana Tech University
Department of Biomedical Engineering
Box 10348
Ruston, Louisiana 71272

A Case Study in Accessibility for a Worker in a Public Building

1.5

Albert E. Swarts
Consulting Engineer
Houston, Texas

INTRODUCTION

The distinction between independent living and job site modification is somtimes difficult to make. Independent self care on the job can be a serious barrier to obtaining employment. This author has been called to make job site modifications several times where he found that the employee's ability to use the rest room independently was at least as great a concern as his ability to perform productively at the work site. The concern expressed by co-workers implied that they might be willing to bring things to the worker at his job, but they found it repulsive to aid in rest room activities.

This situation emphasizes the need for accessibility in public buildings. While most building codes require design for the disabled, many problems still exist. Older buildings are still in use, errors and oversights are made in new designs, and the needs of the more severely impaired are not fully addressed yet. This paper reports on a specific problem addressed by a rehabilitation engineer. He was called to investigate the needs of a young lady limited by multiple sclerosis and working as an accountant for a large energy firm. She and her employer had complained of her limitations caused by her inability to open certain doors in the building. One of these doors was an area separator through which she had to pass occasionally to perform her job. The other was on the women's rest room. She also complained that she found the "accessible" toilet more difficult to use than the conventional one.

To the employer's credit, the company was prepared to pay for the modifications needed or to negotiate with the building owner if the cost of the modifications was reasonable. The challenge to the engineer, then, was to find a good solution at a reasonable cost that could show some economic justification. To this, the company added the limitation that it would be moving to new quarters in eighteen months.

ANALYSIS

The most readily observable cost to the employer was the labor cost of the lost work of a co-worker when she had to be interrupted to aid the woman in going to the rest room --- for no other purpose than to open the door for her to get in and wait until she was ready to leave. Since it is common industrial engineering practice to allow about 5% of a worker's time (24 minutes in an eight hour day) for personal time (1), these calculations are applied only to the co-worker's time.

The data needed to calculate the exact cost of disrupted work would be impractical to obtain within the scope of the study, and it is questionable if the answers would have much greater accuracy than those calculated from estimates. This is justified by the purpose of the study, which is to relieve a human problem quickly rather than to gather scientific data.

The assumptions were kept conservative so they would be easier to defend to the employer. Very little consideration was given to the overhead cost of benefits that the company has to pay for an employee's time. Four weeks of vacation and ten holidays per year were used in the calculation. The assumptions are as follows:

1) $6.00 per hour cost to the company for co-worker's time

2) 20 minutes per day: 2 trips per day of 10 minutes each

3) 46 weeks of work per year

Calculations:

20 minutes x 5 = 100 minutes/week
100 - 60 = 1.67 hours/week
1.67 x 46 = 76.67 hours/year
76.67 x 6 = $460.00/year
$460.00 x 1.5 = $690.00 for the 18 months that the company would be in the building

This gave a basis for comparison of the cost of installing modifications.

Since the worker did not have the strength to pull the doors open, the next step was to see if her "Amigo" vehicle could do it. The vehicle demonstrated a pulling power exceeding 20 lb in low range and three times that in high range. The doors required a measured pull of 17 lb. to open. It appeared that the vehicle should be used if a system could be devised.

Pushing the doors open proved to be relatively easy. Once the worker was instructed in the mechanical advantage achieved by pushing at the edge of the door instead of in the middle, the vehicle opened the door easily. Once she was in the rest room, the engineer was faced with the problem of getting her out. While the vehicle had adequate power, the motion required would be tricky. The worker would be required to back up, push the door far enough aside and move the vehicle far enough forward to get into the doorway before the door closed in front of her. It seemed to be unreasonable to require the worker to learn this kind of performance. Also, there seemed to be no convenient structural member on the vehicle to carry the load.

The next consideration was to devise a system that would open the door with a continuous forward motion. The choice was a rope and pulley system that came across the rest room at ceiling level and down to a level of about 2½ feet by the inner door. (figure 1). Calculations of the open and closed positions showed that the system would require 3' - 4" of movement to get the door open. Figure 1 is drawn to scale and shows that there is enough space in the room, but none to spare. The system would require the worker to have a quick release hook on the side of her vehicle to permit her to disengage when she got into the doorway.

One concern the engineer had was the droop in the overhead line when the door was opened without using the system. Would the 1/8" braided nylon cord be low enough to cause annoyance or hazard? Since this is a uniform cord or cable freely suspended from two points, the curve formed is a cantenary (2).

$$y = c \cosh (x/c) \quad \text{(i)}$$

C is unknown and is calculated by trial and error from the known length(s) of 128 inches:

$$s/2 = c \sinh (x/c) \quad \text{(ii)}$$
$$c = 28.28$$

Returning to equation (i), and calculating the value of y at the mid point (3½ feet or 42 inches) gives a sag (y - c) of 41.38 inches. With a 9 foot ceiling, the clearance is less than 5' - 7". This is definitely annoying, and it could be a hazard to a tall woman in high heels. The solution is to weight the section of the line travelling down beside the inner door. This gives an added benefit of keeping tension on the line over the pulleys. The tension will make it less likely for the line to jump out of the pulley.

This system can be installed for less than $100 in materials and $100 to $200 in labor. This would be a cost savings to the company in light of the lost time with the existing situation. Maintenance of the system, however, could be a problem, and the building owner might object to the appearance of the system. Discussions with the building manager revealed that he was willing to consider the system, but he also wanted to know how it compared to a powered door opener.

Investigation of commercial systems uncovered a light duty system that was adequate for the application. The Keane Monroe Series 100 door operator is capable of serving as powered door closer when the door is opened manually. It requires no clearance over the door other than the door frame. The cost is $550 plus about $100 for installation. The powered system appeared to have a lower potential for maintenance problems, and was capable of meeting the needs of a larger population. Therefore, the engineer presented both options and recommended the commercial system rather than his own design.

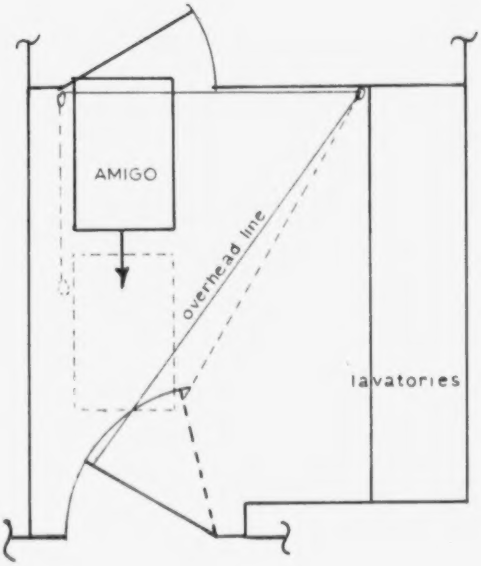

Figure 1
Door Opening System

Investigation of the toilet revealed that the grab bars were mounted on the wrong wall (Figures 2 and 3). Since the rigidity of the plumbing made it impractical to move the toilet, the apparent solution was to move the bar to the other wall. This wall, however, was a floating panel anchored only to the back wall. It was incapable of supporting a woman's weight. The only remaining solution was to install an L - shaped grab bar anchored to the back wall and to the floor.

The last to be addressed was the door separating the main hall from the side hall with its suite of offices. The worker had to pass through this door periodically to get to the computer terminals when she needed to use them. She did not need it often enought to justify her own terminal, and disruption caused by her use of this door caused annoyance. However, it was difficult to identify any significant concrete cost to the company.

The purpose of the door is to permit the tenant to shut off the area from the main traffic area and provide security if desired. The question of fire code requirements was raised, but a smoke barrier was not required for areas of less than 50,000 square feet (slightly more than one acre). The building manager asked for a ruling from the fire inspector, and he verified that there would be no violation

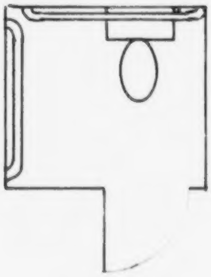

Figure 2
Existing Water Closet

if the door were left open. The engineer's recommendation, then, was to remove the door closer and close the door only at night. Even if the door were closed, the worker could open it if she did not have to fight the 17 pound force of the door closer.

SUMMARY

The purpose of this project was to improve the lot of one particular person in the context of one job at one company. The assignment was to come up with a workable solution (not necessarily the best) with a maximum of two day's work. In this time, the engineer had to work out more than one solution so the employer would have information to make a choice.

The choice presented to the employer and building manager was between a custom designed system for one person and a commercially available system that cost twice as much but had greater capability of serving more than one person. The analysis of the cost of lost working time was done to determine if the systems were economically justifiable. In this case, both systems could pay for themselves in the time frame allowed. This may not always be true.

ACKNOWLEDGEMENTS

An engineer applying technology to the needs of disabled people and their employers has not divorced himself from research organizations and their efforts. In the limited time allowed, research professionals can help with their broad knowledge of new developments. This author acknowledges valuable support from the Texas Rehabilitation Engineering Center. The file information on available technology from the IMPART program of the Texas Rehabilitation Commission and Southwest Research Institute were made available to him. Without this support from their information network, the inexpensive door opener that was recommended could not have been found in the time allowed.

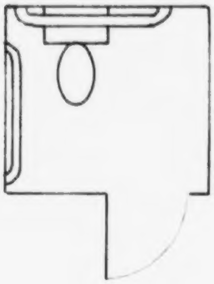

Figure 3
Guidelines for Water Closets (3)

REFERENCES

1. Barnes, Ralph M., Motion and Time Study: Design and Measurement of Work, Seventh Edition, John Wiley and Sons, New York, 1980, p. 307.

2. Middlemiss, Ross R., Analytic Geometry, Second Edition, McGraw-Hill, New York, 1955, p. 179.

3. United States Architectural & Transportation Barriers Compliance Board, A Guidebook to the Minimum Guidelines & Requirements for Accessible Design, U. S. Government Printing Office, Washington, 1981, p. 44.

1.6

HOMEBOUND WORKSITE MODIFICATIONS

Phillips, G. N.

Southwest Research Institute

ABSTRACT

Two separate worksite modifications were created for disabled veterans having distinctly different worksite requirements but were both in homebound environments. One site modification required considerations of the individual's home training program as well as extreme space limitations. The second site required developing an existing bed into an office desk with dual functions. The user was self-employed/owner of a wheelchair repair business who needed a workstation which projected a business-like atmosphere. In solving the worksite adaptations, the users were encouraged to participate in all phases of the concept, planning and design.

INTRODUCTION

The worksite modifications developed by the rehabilitation engineering staff were accomplished under a Veterans Administration contract. Some of the proposed key elements were to identify the appropriate veteran with a handicap and determine that he/she is "job-ready"; has a realistic vocational goal; development of an appropriate work or work-training site; applications of rehabilitation engineering has merit.

BACKGROUND

Home Training Worksite (Paraplegic-Wheelchair Assisted)

A homebound individual was enrolled in a woodworking training program which would require extensive use of powered tools. The training would be conducted at the client's barrier-free residence which had been constructed without regard to future training activities. Due to the nature of this vocational training, the 600 square foot garage was selected as the work-training site. A preliminary site survey by the rehabilitation engineering staff revealed inadequate power sources, low ambient light levels, and an untreated concrete floor. The training program appeared not to be progressing because of the lack of a viable shop floor plan and the equipment was generally too high to safely operate from a wheelchair. An intense effort was initiated to establish a viable training/worksite through modifications to the dwelling and the workshop equipment.

Business Oriented Worksite (Quadriplegic-Bilateral Amputee Above the Knee - Wheelchair Assisted)

A homebound individual was self-employed as the owner of a wheelchair repair business. Although wheelchair assisted, his impairments required him to spend a high percentage of his active hours in a bed. The repair business, located in a residental structure, was accessable but all interaction with customers was limited to one small room which also served as his primary living quarters. An adaptive workstation was needed to promote a more business-like atmosphere. To conserve space, this workstation needed to be integrated with his existing bed. A secondary requirement was to provide work space for an administrative staff member.

MATERIALS AND METHODS

Home Training Worksite (See Figure 1)

Shop Floor Plan. To encourage acceptance of any floor plan and associated adaptations, the client was invited to actively participate with the engineering staff in formulating an overall concept. The objective was to find the optimum solution which would enhance the training program and provide for shop adaptations. Several meetings occurred before a shop plan began to solidify. To arrive at the final solution, a chalk outline of equipment was drawn upon the concrete floor so the client could visualize the layout.

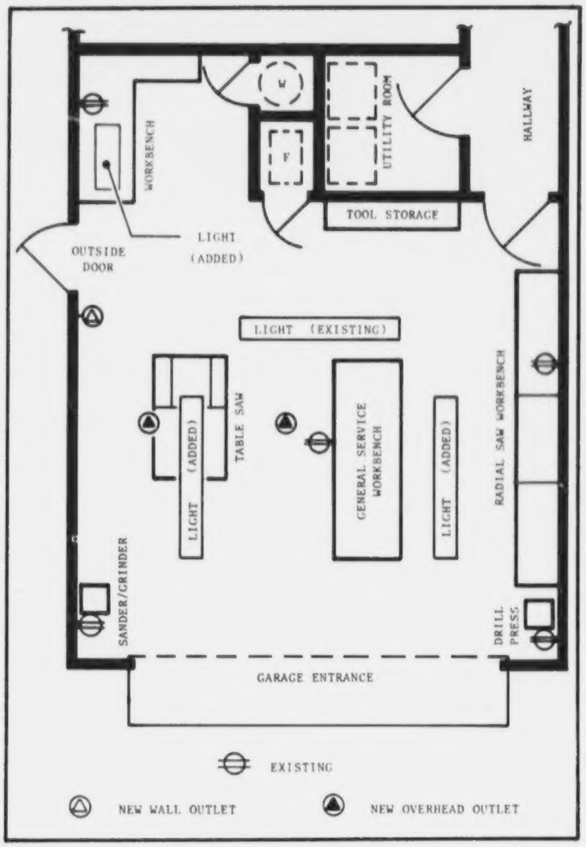

Figure 1. Shop Floor Plan

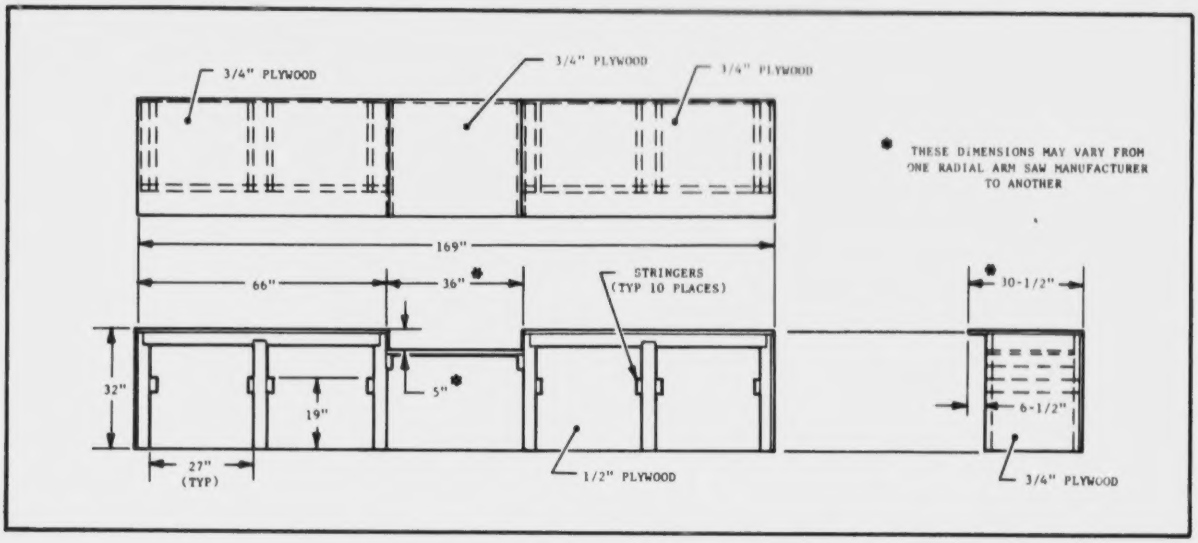

Figure 2. Radial Arm Saw Workbench

By maneuvering his wheelchair, the client verified that shop flow control could be achieved and the plan would meet his needs. Figure 1 delineates the shop floor plan which was implemented.

Shop Floor Treatment. As the shop floor plan began to develop, it became very evident to the client that shop debris and spillage were going to present a large problem in the worksite area. The client had been experiencing difficulties in cleaning the concrete floor due to surface roughness and the associated dust accumulations. The rehabilitation engineering staff recommended a polyurethane floor treatment which is used throughout the manufacturing industry because of its ability to survive daily wear, abrasion and impact. These surface treatments resist soiling, stay cleaner and are highly immune to chemicals/solvents. Due to fund limitations, the client elected to petition a paint manufacturer for the necessary materials. In return for materials, the manufacturer would receive the client's evaluation delineating apparent success and/or failures. The request was granted by the manufacturer. The rehabilitation staff and client applied the coatings per instructions. Not only did the floor cleaning problem virtually vanish after the treatment was applied but ambient light levels increased noticeably.

Work Benches and Equipment Modifications. Concurrent with the shop floor plan considerations, designs for the appropriate work benches and tables were formulated. Design concepts for all benches and cabinets were developed with the client by assessing his available motions, including maximum reach. The radial saw was the clients greatest equipment concern. Supporting materials while operating the device posed a serious safety question. Utilizing a widely used shop design, a sawing bench was fabricated and installed at the worksite (see Figure 2). It was necessary to modify all commercially purchased power equipment (table saw, sanders, etc.) to lower them to a usable height.

Lighting and Electrical Modifications. A survey by the rehabilitation engineering staff revealed that the existing power distribution and lighting were insufficient to support the worksite. The recommended electrical power modifications (see Figure 1) and two recessed fluorescent lights were installed by an electrical contractor. Two electrical twist lock "down" cords were provided to the client so that power could be accessed in the open areas of the worksite using the ceiling mounted receptacles.

Business Oriented Worksite

Preplanning Phase. Transforming an area being utilized as private living quarters into a shared business worksite requires careful preplanning. Vocational goals and daily living requirements must be carefully examined. Intense interaction between the user and the rehabilitation engineering staff was required to assure that the future modifications will be appropriate and provide a positive impact upon the environment. Numerous preplanning sessions were required before a final determination to proceed into the design phase was reached.

Design Development. Interface of the desk with the bed was the first design element considered. It was determined that the desk be removable from the bed rather than hard fastened to it. This allowed some degree of serviceability to both components in the event of a malfunction. The design chosen was one which allowed the desk to be cradled over the bed and be supported bv the head and foot boards (see Figure 3).

The second design element was to determine relationships between the user and the proposed work-surface. To finalize this relationship, a cardboard "mock-up" was utilized. A series of cardboard elements were taped into place and repositioned as required to ascertain the correct height, width and lengths. The correct height for this workstation could be maintained by electrically actuating the bed up or down. To maximize the utility of the desk, an additional work surface was provided at opposite sides of the desk providing a workstation, near the user, for administrative activities by employees. To provide accessibility for attendants, the desk top was designed to translate towards the footboard on slide tracks. A pivot point was established on one leg of the bed so that the bed/desk could be rotated for additional accessibility. As the design neared completion, the user expressed a need to foreshorten the bed to conserve on space. Since the majority of the leg space on the bed was not utilized, the bed was modified by removing approximately 18 inches at the foot-end. All measurements and design details were incorporated into the final engineering drawing which was used to construct the desk.

Fabrication. The engineering drawing was submitted to a cabinet shop for fabrication. A hardwood veneer was selected to be used in the basic construction. Plastic laminate material was used on all working surfaces to add durability. To provide a stylized appearance, additional plastic laminates were used as accent panels. A dark walnut stain was applied and finished with a urethane coating. The bed frame was shortened by removing a selected section and rewelding. This modification required that the actuator rods connected to the bed and motors to be foreshortened also.

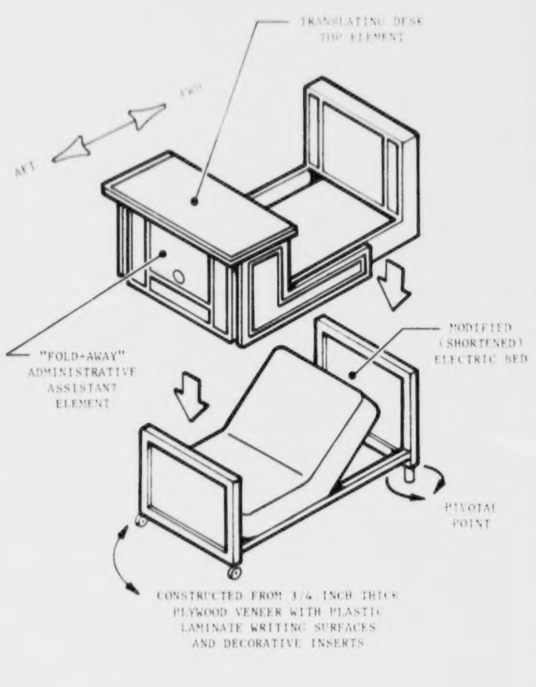
TRANSLATING DESK TOP ELEMENT
FWD
AFT
"FOLD-AWAY" ADMINISTRATIVE ASSISTANT ELEMENT
MODIFIED (SHORTENED) ELECTRIC BED
PIVOTAL POINT
CONSTRUCTED FROM 3/4 INCH THICK PLYWOOD VENEER WITH PLASTIC LAMINATE WRITING SURFACES AND DECORATIVE INSERTS

Figure 3. Desk/Bed Modification

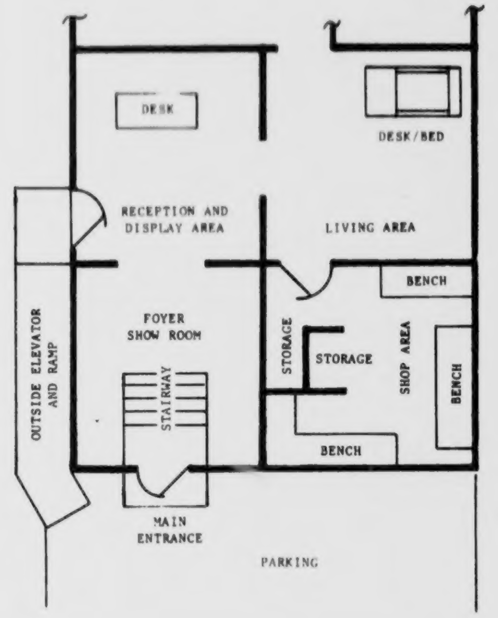
DESK
DESK/BED
RECEPTION AND DISPLAY AREA
LIVING AREA
BENCH
FOYER SHOW ROOM
STORAGE
STORAGE
SHOP AREA
BENCH
OUTSIDE ELEVATOR AND RAMP
STAIRWAY
BENCH
MAIN ENTRANCE
PARKING

Figure 4. Business Floor Plan

RESULTS

Both the home training site and the desk/bed adaptations were effective solutions to disabling problems. The individual in woodwork training has completed his course instructions and completed several worthwhile projects including restoration of furniture. The desk/bed was fully utilized by the client in his business and he later added additional adaptations. The desk/bed furthered his independence and provided an excellent business image.

CONCLUSION

The simplest worksite modifications for impaired individuals yield the best possible results. This concept of site modification becomes extremely important when altering homebound sites where available space is extremely limited.

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Hughson Chemicals/Lord Corporation

Vickers Industrial Coatings

Southwest Research Institute
6220 Culebra Road
Post Office Drawer 28510
San Antonio, Texas 78284

Devices to Aid in Independent Living

Elmer A. Hoyer
Winifred D. Brandt

Rehabilitation Engineering Center - CPR/WSU

ABSTRACT

As a part of its involvement with a housing unit for the handicapped, the Wichita REC has evaluated 8 communication devices for use with the verbally handicapped. They were evaluated with respect to their acceptability to the user, capability, cost and service. Included were devices with various modes of activation and various modes of output such as printers and voice snythesis. One unique part of this evaluation was that the potential users, the residents of the housing unit, determined the acceptability of the devices.

INTRODUCTION

During the past several years, the REC, co-sponsored by the Cerebral Palsy Research Foundation of Kansas, Inc. and the College of Engineering, Wichita State University, has provided engineering research and support for the Timbers housing project. The Timbers, a HUD supported project, consists of 100 apartment units for the physically handicapped. Of these 100 units, 24 units are reserved for severely physically handicapped individuals. These 24 apartments, together with a dining hall and a center for attendant care delivery, form what is called the congregate area. Virtually all of the 24 individuals renting these apartments require some form of attendant care on a daily basis. Some of the tenants are classed as non-verbal and non-manual. The extent of REC involvement with the Timbers has concentrated almost exclusively in the area of assisting these severely handicapped individuals to become more independent in their daily living through devices to enable them to request attendant care and to make their needs known to attendants. Multiple systems have been developed and commercially available devices were evaluated which would assist these individuals with their communication problems. Other problems, such as door locks, meal preparation, etc. were investigated with regard to aids which may be available to assist in gaining independence.

The primary population of this study are the tenants at the Timbers Complex, specifically the 24 individuals who are severely involved and represent varying degrees of disability. This population has proven in the past to be extremely valuable in that they have been receptive to new research ideas and because they are very critical in terms of worth and desirability of new devices to assist them in their desire for independence.

DEVICE EVALUATION METHOD

A distinct part of any evaluation of devices for use by handicapped individuals must include an evaluation by the handicapped user. Therefore, each device purchased and evaluated as a part of this study was placed with a handicapped user for an evaluation. After adequate time was allowed for becoming familiar with the device, the handicapped user was questioned relative to his/her opinion of the device; both the device's strengths and weaknesses were identified from the user's viewpoint.

In addition to the evaluation by the handicapped user, the devices were also evaluated by members of the Wichita REC relative to the number of features provided, the ease with which these features could be used, and the cost of the device. The type of construction utilized to manufacture the device was also evaluated relative to its sturdiness and general appearance. While appearance is only an esthetic quality and not a functional quality, it is still considered to be an important parameter to be considered. They should, as much as possible, appear like devices utilized by able-bodied individuals and should not set the handicapped user apart as someone different.

In addition to evaluating the capability and construction of each device, the availability of repair service was determined, where possible, and the expected frequency of needed servicing was estimated. Too often devices for the handicapped user are produced and sold with no repair service structure considered. When the device fails, the user generally must send the device back to the manufacturer for repair, thus depriving this individual of its use for extended periods of time.

COMMUNICATION DEVICES

A total of 8 communication devices have been evaluated and are being reported on. Some of these devices were purchased strictly for the purpose of evaluation while others were purchased by the clients and loaned to us for evaluation. In one case, that of the Ability Phone, the device was loaned to us by the manufacturer for our evaluation.

Zygo

The Zygo communication aid (model 16C) is a relatively large, lightweight panel utilizing a varible scan rate and variable number of selection choices. It is easy for an able-bodied person to change overlays in order to change vocabulary selections. The Zygo was easy to learn to use and would be useful when teaching someone in the use of scanning devices. This scanner contains no memory for pre-stored messages. The switches and associated circuitry used for word selection were found, by many of the users, to respond too quickly. An individual with poor muscular control, a characteristic quite often associated with cerebral palsy, many times activated a switch twice in the process of making a selection. This fast response time causes both hits to be recorded when only one of the hits was desired. No adjustment was provided in this device to slow this response time. The device was also felt to be rather expensive when compared to the capability provided.

Canon

The Canon communicator is a small device containing an alphabetical and numerical keyboard and a strip printer providing a hard copy of the message. The device was very pleasing to the individuals, in that it resembled many able-bodied devices and thereby not setting the handicapped user apart as someone different. The device can be operated through the use of fingers or various headsticks by adaptive devices available for activating the keyboard. The printer is silent and very readable. It requires spelling since no pre-stored words or messages can be contained in the unit. It is operated from a battery pack and cannot be run directly off an AC adaptor. The cost of this device, while rather high, is not entirely out of line considering the hard copy capability.

Memowriter

The Sharp Memowriter is one of the most inexpensive communication devices available on the market containing hard copy capability. This device is marketed for the able-bodied individual and, therefore, looks like an able-bodied device. It has a keyboard arranged like a typewriter and has the capability for messages to be typed directly from the keyboard or to be stored in memory for later recall. There are 40 memory locations, each capable of storing a phrase or sentence. This device is small, easy to carry, and can be operated either from the internal battery or from an AC adaptor. However, due to its small size, it does require fine motor control to operate and requires some spelling, but only if messages are not already stored in its memory. The unit can be serviced at any Sharp repair center which should reduce the downtime.

Expanded Keyboard Memowriter

There is also an adapted Memowriter put out by Prentke Romich Company which has the same features of the original Memowriter. In addition, the Expanded Keyboard Memowriter has an enlarged keyboard permanently mounted to the Memowriter, eliminating the requirement for fine motor control by its users. It is still easy to carry but is much larger than the original Memowriter and is not as attractive as the small unit. The cost of this adapted unit has increased significantly. The keyboard requires a certain amount of strength to activate the keys and the multi-function keys are not color-coded as the original keyboard had been designed. This creates some problems in interpretation of the functions being activated. Also, the device no longer looks like an able-bodied device but rather a special device for the handicapped user. Service for this device requires sending the unit to Prentke Romich.

HandiVoice

The HandiVoice, marketed by Phonic Ear, is a voice synthesizer unit based upon phonemes and is one of the first synthesizers packaged as a communication device for the non-verbal individual. The upper surface of this device is a matrix array of switches with each switch activating the voice output of one of four possible words or phonemes. In addition to the matrix of switches, there are four switches which choose the level from which the matrix operates. The device does have memory capability for complete sentences to be built and stored and being spoken on the speech command. New words not contained in its permanent memory can be formed if one knows the phonetic alphabet. There is good volume control and reasonable pitch control but the voice is always a male voice and to some, the voice appears to have an accent. Some single words spoken by the device are unrecognizable, however, when used in the context of a sentence, most words are recognizable. There is no flexibility offered by the manufacturer in the organization of the words on the unit or in the word selection. The switches used for word selection were difficult for some users to activate, particularly when using a headstick. There is a scan select model available for headstick users, but this unit requires that a 3 number code be used for each word selected. The AC adaptor available for the device is for battery charging only and not for continued use. The cost of this unit was considered to be rather high for the population utilized in this study. Also, the unit was found to be heavy and difficult to use when in a wheelchair. Service for this device is handled by Phonic Ear.

Express 3

The Express 3, manufactured by Prentke Romich Company, is a programmable communication aid where each location can contain in memory up to 8,000 characters. The device has printer capability and can print complete messages. The unit can be put in either a scan mode or in a direct selection mode. While this device was advertised to have voice synthesis capability, the synthesizer was not available at the time our client received his communication aid. He was told by the company he would have to send it back in about 3 months for the synthesizer to be added. The only service available for this device is through the primary company. We found the concept behind the device relatively easy to understand, but somewhat difficult to use when words were stored and then recalled. The unit is rather large, somewhat clumsy and does not have the appearance of an able-bodied device. When used with an individual in a wheelchair, a mount is needed in order to place it on a wheelchair. Without this mount, it would be difficult to handle by a person in a wheelchair.

Vocaid

The Vocaid, built by Texas Instruments,is an inexpensive and small voice synthesizer communication device. It has no hard copy capability, a rather limited vocabulary; the voice is clear but with relatively poor volume control for the voice. It does have an option available for additional volume to the voice. There are four overlays for the device which changes the vocabulary to be used. These overlays are somewhat difficult to change, particularly for a handicapped user with limited physical capability. Only one level, corresponding to one overlay, can be used at any one time. As a result, it has limited capability as an all around communication device. The unit can be utilized from either two D size batteries or AC adaptor. The unit is fairly inexpensive and easy to carry. Service for this device is handled by Texas Instruments.

Ability Phone

The Ability Phone, manufactured by Basic Telecommunications Corporation, is designed to be both a telephone communication aid and an environmental control unit. This unit has many different functions which it performs, one of these being communication by way of a voice synthesizer. The quality of voice is by far the best these investigators have found. The appearance of the unit is pleasing and looks like an able-bodied device. In order to utilize the functions which this unit can perform, the user scans through a menu to determine which function is to be performed and to set the parameters. Several of the individuals who used this device found it difficult to use due to the complexity of the menu. It has limited capability as a communication device, but the voice quality is good and it uses standard off-the-shelf BSR devices in conjunction with its ability to perform as an environmental control unit. This device was not designed as a communication device but rather as a telephone and as an environmental control unit. The cost of the unit is considered to be reasonable for the functions it has. To repair the unit, it must be sent back to the manufacturer.

OTHER DEVICES NEEDING EVALUATION

One major obstacle to independence in daily living for the severely handicapped individual is negotiating keys and locks for house or apartment entrance. To the individual with manual dexterity problems, such as those with cerebral palsy, unlocking a door with a key can be a major task and many times impossible. There are pushbotton-type locks available on the market where a combination is entered by pushing a series of buttons and the door is unlocked with the use of a key. The cost of these locks tend to be very high compared to the cost of a standard deadbolt lock.

In addition, no evaluation has been done yet on these locks to ascertain the force required or the manual dexterity required for negotiating this type of lock. A survey is currently being performed to determine what locks are commercially available and an evaluation will be made to determine the capabilities required to negotiate the lock. In addition to locks, door openers also need to be investigated to determine what is available on the market.

Another task which many handicapped individual find difficult to accomplish is that of meal preparation. One particular application which has been cited by tenants of the Timbers as difficult to handle while sitting in a wheelchair is the oven door. Most microwave ovens are side opening, however, standard ovens, as found with commercially available ranges, either built-in or free standing, typically open down. With the door opened, it is extremely difficult to remove a dish from the oven while in a wheelchair. A side opening oven door would appear to be much easier to handle when removing hot dishes while sitting in a wheelchair. This whole area of meal preparation needs to be looked at in terms of devices which would aid the handicapped individual perform his/her tasks independently.

REFERENCES

1. Basic Telecommunications Corporation
4414 East Harmony Road
Fort Collins, Colorado 80525

2. Canon U.S.A., Inc.
10 Nevada Drive
Lake Success, New York 11040

3. Prentke Romich Company
8769 Township Road 513
Shreve, Ohio 44676

4. Sharp Electronics Corporation
10 Keystone Place
Panamus, New Jersey 07652

5. Zygo Industries, Incorporated
Post Office Box 1008
Portland, Oregon 97207

6. Phonic Ear, Inc.
250 Camino Alto
Mill Valley, California 94941

7. Texas Instruments, Incorporated
Texas Instruments Repair Service
Post Office Box 2500
Lubbock, Texas 79408

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QUANTIFICATION OF THE ARCHITECTURAL NEEDS OF THE PHYSICALLY DISABLED

WILLIAM L. WOODS

University of Arizona Health Sciences Center

ABSTRACT

The University of Arizona has conducted three research projects since 1978 to more precisely describe the functional architectural requirements of handicapped people. Two of these projects were funded by the National Institute of Health and one by the United States Architectural Compliance Board. These grants were administered by the Southwest Arthritis Center of the University of Arizona and the National Bureau of Standards. The actual work was carried out by the Biomedical Engineering Department of the Arizona Health Sciences Center.

Two of the projects were carried out in Tucson, Arizona. They tested 225 people with arthritis in one multi-faceted study and 80 people with all types of ability in another project studying doors. A third project was basically a repeat of the arthritis grant but studied every every type of disability that we could enlist. This latest study was conducted in Green Valley and Phoenix, Arizona and concluded in April, 1983. Over 400 people were tested in these three studies.

The projects ranged from one to two and one half years in duration with yearly budgets of approximately $25,000 per year. In all three cases, the work was carried out by volunteer and 1/4 time or less part-time staff.

The acquired data revealed that there is a need for more complete and precise specifications of the architectural needs of handicapped people. It also documents situations in which design needs of the total handicapped population go beyond those of the wheelchairbound person.

BACKGROUND

Independent access to public and private buildings has been a problem for handicapped people down through history. In this century the handicapped have become more visible and vocal about their abilities and society has become more enlightened and concerned. Several major wars, the development of the automobile and improved medical technologies have all contributed to the increase in the number of people who suffer and survive catastrophic physically disabling trauma. Today the problems of disabled people are more visible and better appreciated than at any time in history. The cause of equal opportunity for the handicapped is popular and politically credible. We are all becoming aware that when society or when societies or buildings become more physically accessible to the least able among us, they automatically become more accessible to everyone else.

We have been working toward a goal of improved architectural accessibility in our handicapped ergonometric research projects at the University of Arizona. Our work was stimulated by experiences in trying to assist the city of Tucson in developing handicapped accessibility specifications for their city building code in 1977. We were invited to assist in this procedure because of our previous experience in setting up a network of "model homes" in Arizona that demonstrated technological solutions for problems common to people who have arthritis. When the city of Tucson Code Committee surveyed national accessibility standards, it was obvious to us that many of the specifications were too general and not appropriate for many of the handicapped people we had worked with. Also, the codes did not specify many important architectural details that impact on a handicapped user's safety or independent function. Another problem for the committee was that published recommendations of individual authors and national or state building codes did not agree in their specifications. This stimulated one Tucson builder to state that he was willing to modify his buildings in ways that truly helped people, but he was not ready to waste his money on excessive and vaguely stated requirements from politically-motivated bureaucratic sources. He then asked us to supply the committee with scientific data substantiating the needs of handicapped individuals. Unfortunately a subsequent review of the literature showed that generally such data did not exist. Those few studies that had been conducted were so limited in their scope that their findings were more useful as guidelines than specification.

From this experience, it was obvious to us that scientifically-based data was required to accomplish two equally important goals of accessibility design. The first goal is to maximize safe independent access (and egress) for "all people" using public buildings. Equally important is to assure ourselves that specifications for building access are needed, valid solutions stated with sufficient precision to meet the needs of the least able in an economically reasonable way.

METHODS AND MATERIALS

Three pilot studies have been conducted at the University of Arizona to develop data gathering systems for the quantification of the architectural requirements of physically handicapped individuals. These projects do not claim to answer all the pertinent questions for handicapped access. What they have attempted to accomplish is to demonstrate a scientifically-based methodology for the quantification of people's functional needs. In the process, useful and interesting data have been developed.

All three projects have been conducted using the concepts developed in the original study with arthritis. This study sought to:
a) to develop a simple, repeatable system of functionally describing a person (study population), b) to design the tools needed to be able

to quantify a person's functional architectural requirements in a repeatable, valid, precise manner (architectural simulations), c) evaluate a low-cost, portable "assembly line" technique for gathering quantitative data on large numbers of handicapped people and d) to demonstrate areas of architectural design not addressed by national standards while evaluating the appropriateness of existing specifications for specific and more generalized disability groups.

Study Population

The definition of the population that is to be studied is fundamental to the validity of the study. There are two components to this definition. First, the population should statistically approximate the real world frequencies of subject types of people as closely as possible. Secondly, in order to be able to deal with the first concern, we must describe the members of our population in a valid way that expedites their categorization into subgroups.

Our first approach to solving these problems was to define our population by adapting existing techniques for measuring body strength and range of motion. Second we divided the body into its articulating joints and listed those joints that proved significantly less than normal during assessment by a registered occupational or physical therapist. We also noted if the limb was incomplete (due to birth defects or amputation) or had coordination problems. Other facts were gathered about sex, age, height, weight, dominant hand, and style of ambulation or transport. A medical diagnosis was also listed for the cause(s) of the disabling condition. We hoped that gathering all this personal data would allow many different approaches to data analysis versus physical definition subgroup definitions. We hoped that this approach could lead to a less prejudiced evaluation of the population.

There is no existing data or technique to help us define how many people to test in each category of functionally handicapped individuals. There wasn't even data on all the possible combinations of physical disabilities a person might have. It was therefore hoped that our studies might give some insight into the statistical frequencies of disabling conditions. We confronted this problem by deciding to access our study population through advertising as widely as possible in the news media for volunteers who wish to solve or describe their own views on accessibility problems.

Architectural Simulations

Another concern was to develop measurement instruments that were valid and reproducible in their quantification of human performance or preference. Our approach was to simulate real world conditions as closely as possible with portable, adjustable devices that allowed for the quantification of adjustable parameters.

Two measurement instruments were developed for each simulation. The initial instrument was the overall testing plan which specified what was to be investigated and how one conducted each test. This plan was developed by carefully analyzing a particular activity necessary for access to a structure (e.g. walking down a hall, opening a door or climbing stairs), from a functional or biomechanical perspective. An attempt was made to isolate and measure individual components of a complex action measuring them individually. We then combined them in the original activity to confirm the original findings in the more realistic dynamic process. For example, in specifying door requirements, we were concerned with: side or angle of approach, maneuvering floor space in front and behind the door, latch style, latch activational force, magnitude and direction, latch angle of rotation, latch position (horizontal and vertical), initial door opening force, forces required to maintain the door open as you walk through and close it, door opening speed and angle. Obviously many of these parameters are dependent on each other and this complicates and compromises the reality of our test simulations. Due to the vast numbers of variations in such testing systems, we attempted to test standard or commercial options first. The second testing instrument was the engineered hardware that portrayed the physical situation and allows measurements to be made.

Two of our projects used precisely the same equipment. Its portability has allowed us to move it to three different cities. It was first used in Tucson with arthritis patients, then in Green Valley and Phoenix, Arizona, with people with every type of disabling condition that we could enlist in our project. The architectural simulations used in these two studies were: a) an adjustable width door set with adjustable position door latch, b) an adjustable angle (0 - 10 degrees) ramp with adjustable width and height handrails, c) an adjustable depth, width and height stairway with adjustable width and height handrails, d) interchangeable floor surfaces, e) a set of moveable corridor walls, and f) an adjustable height wall set on which was mounted fire alarms, light switches and door latches that measured applied force.

The third research project studied door requirements for the physically disabled. This door simulation was more sophisticated than the original studies! It appeared more realistic in its configuration and incorporated an electronic door angle measurement system that also measured angular velocity and acceleration. This design also allowed for the application of an constantly applied closing torque on the door. Other hardware features of this study were multi-surfaced pathway, movable walls and a the introduction of a standard "reproducible" floor surface by using masonite sheeting.

From the hardware and testing plan, we then developed a document we called the testing protocol. This prompted the testing team as to what was to be tested next, how to set up the equipment and gave testing dialogue so that questions were asked in a repeatable fashion.

Testing Procedure

In each of our studies, we specifically recruited architecture and interior design students to be our primary research assistants. This was done to enrich these students educational opportunities. Our hope was that these students would leave our program with a heightened desire and knowledge of how to incorporate handicapped people in their designs.

Each volunteer's testing session was limited to two hours. In the door study, many of the people volunteerred to return for multiple testing sessions. In the other two studies, a two hour session was geherally sufficient to accomplish the required work.

The testing sessions began with a preliminary physical assessment by a registered therapist. The therapist served as our "lifeguard" and team leader. They pointed out any safety problems the individual might have with our testing procedure and monitored the students testing technique for safety and quality.

The volunteer then randomized his own testing order by drawing cards labeled with architectural simulation titles from a box. This precaution was taken to minimize biases that might appear in the data due a test having a constant position in the testing procedure.

Next, the two student researchers presented the test situations to volunteer over a two hour period. A set of cards with the testing protocol were available at each test station. The students read the questions to the volunteer from the cards and adjusted the equipment as the cards directed.

At the end of the test session, the volunteer was interviewed as to their opinions, suggestions and complaints about our test and architectural accessibility in general.

Results

We believe that our studies have show that large scale anthroprometric and ergonometric research with the handicapped is feasible and can be accomplished in a fairly inexpensive fashion. All three of our projects were carried out with small budgets for time and money.

The "Requirements of Door Design for the Physically Disabled". was funded for under $30,000 and approximately a one year period. Everyone on the staff was part time including the principal investigator who was on 1/4 time.

"Disability and Building Codes: A Quantitative Study" (phases one and two) were both funded at approximately this same level of ($25,0000) per year for 2 and 2 1/2 year periods respectively. As in the "Doors" study everyone involved was on a volunteer or part time basis.

The "Disability and Building Codes: A Quantitative Study" two phase study demonstrated that our research methodologies could travel from city to city to achieve our goals and thus access larger or more diverse populations. These two phases were basically the same study differing only in the location and the study populations. Phase I was conducted in Tucson with 225 volunteers with some form of arthritis. Phase II was conducted in Phoenix and Green Valley, Arizona with volunteers with any type of disability. The "Requirements of Door Design for the Physically Disabled" was conducted in Tucson using all types of volunteers also.

Much worthwhile data was developed in all three studies. Some of it was surprising and some confirmed our preconceived opinions.

The "Disability and Building Codes" studies each asked over 100 questions of each individual in a two hour session. The "Requirements of Door Design;..." asked approximately three to five hundred questions depending on the volunteer's time availability and interest in coming back for multiple sessions.

Some generalized statements can be made from our data and interviews. First there are many design details that accessibility standards and do not consider that are of functional significance to handicapped people. For example, the mechanism style of light switches, fire alarms and door knobs are just as important to some handicapped individuals as is the devices' location. Also there are many accessibility specifications that are of more significance to the non-wheelchair bound than they are to the wheelchair bound. An example of this is that we found a blind persons with a "seeing eye" dog requires more maneuvering space through a door than a wheelchair bound person. Another interesting fact we documented was that some people cannot use that same ramp slope or stair height coming down as they required going up.

CONCLUSIONS

Our studies have confirmed the fact that their is a need for more areas of specification in accessibility codes. They have also shown that many of the design guidelines are not appropriate (correct) for some segments of our handicapped population. Some of our testing further documented the fact that the wheelchair is not always the worse case design situation for function or acessibility. There are some situations where people with or without walking aids have the greatest needs.

Ultimately our studies show that there is a need for more ergonometric data on the architectural requirements of the physically handicapped in order to approximate equality for everyone in independent building access and egress. The projects further show that such work can be accomplished in a portable and realitively inexpensive manner.

An Adaptive Microcomputer-Aided Independent Living System For Severely Disabled

Stan Cronk and Roy W. Schubert
Biomedical Engineering Department, Louisiana Tech University
Ruston, Louisiana

ABSTRACT

An adaptive microprocessor-based independent living system, called ADAPTER, has been developed using a standard microcomputer along with a plug-in custom printed-circuit board. The system in its present form is self-monitoring. A description of the operation of the system is provided and an analysis of its utilization presented. Usages of the system beyond independent living and communication are also discussed.

INTRODUCTION

A number of environmental control systems for severely handicapped individuals, built primarily with discrete electronic components, have been commercially available for years. In a study by Sell and Stratford (10,11) several of these commercial systems were evaluated by high level quadriplegics over a 44 month period. Of all the units tested, patients found only the ECU-1 and the ADT-5A (a telephone dialing system for use alone or in conjunction with the ECU-1 system) to be acceptable for home use. Commercial systems such as those used in the study are expensive due to lengthy development times and are more prone to failure because of the nature of assembling complex electronic component systems.

The advent of microprocessors and associated integrated circuits has brought about a revolution in the use of computers. The nature of microprocessors allows implemenation of systems such as for environmental control through a combination of software and hardware. The use of software allows faster development time and a reduction in hardware. The usefulness of microprocessors as processing bases for an environmental control system (ECS) was recognized by Bowjanowski in 1978 (1). Many other researchers are now investigating the use of microprocessors in aids for the handicapped (3,7,8). Most are concentrating efforts in the development of single board computer systems. Though this design strategy will allow development of more inexpensive aids, such systems generally serve only as dedicated aids for a single task, as environmental control or communication. The Biomedical Engineering Department at Louisiana Tech University is currently developing an independent living/communication aid for severely handicapped through the design of a plug-in hardware module for a commercially produced home computer along with appropriate controlling software. This strategy has two principle advantages over the single-board systems:

1) software development time is shorter because the computer's resident operating system and a high-level language (in this case, BASIC) may be used to program most tasks. Once an algorithm has been debugged, reprogramming it into assembly language, if necessary, is much simpler.
2) Use of a commercial computer allows the user to take advantage of commercial software and hardware, servicing network, and reasonable cost available for that computer.

MATERIALS AND METHODS

Description

A General Purpose Interface (GPI) to be used as a communication aid/independent living system (6) has been developed principally with "off-the-shelf" hardware, consisting presently of a Commodore PET 2001-32 microcomputer, a dual floppy disk drive, a printer, a Duophone unit for phone communication, and up to 256 BSR modules for on/off control of lights and appliances. The Biomedical Engineering department developed both a custom-made printed circuit board for input/output and the software to allow the user to control the computer's actions. The circuit board, which plugs directly into the computer's user port and therefore requires no modifications of the computer, accepts control signals from both the user and the computer and implements the computer's signals to control the user's environment. The software allows the user to command the computer through use of either its keyboard or a switch (controlling a scanning or encoding routine) provided to the user. The software offers the options available to the user by presenting individual menus, or lists of selections, each with a different function. Functions presently available to the user include: environmental control, telephone dialing, creation and storage of messages on a highlighted field at the bottom of the CRT screen, and utility functions to alter scanning speed, provide aural feedback for a moving cursor, transmit messages from the screen to a printer for permanent storage, and sound an alarm.

The menus are:
1) SYS - This menu contains the names of all other menus which the user can access as well as certain utility commands such as WRITE to printer and ERASE messages.
2) MODE - This menu allows the user to choose from one of three major selection techniques, as described by Brown, et. al. (2).
3) LETTERS - This menu presents letters and numbers for creation of messages and telephone numbers.
4) WORDS - This menu presents a list of commonly used words which the user can select for use in messages.
5) ENVIRONMENT - This menu allows the user to alter the state of electrical appliances and lights. The circuit board plugged into the user port sends the appropriate control signal via the house wiring (carrier current) to a commercially available BSR module to which the appliance is attached for the actual activation/deactivation process.

6) PHONE - This menu allows the user to make telephone calls by creating a phone number using the LETTERS menu or by selecting a number from a user-modified list.

7) CALCULATOR - This menu allows the user to perform calculations using the four basic arithmetic functions along with change sign, square root, and exponential notation functions.

8) MENU CHANGE - This menu allows the user to make changes in the PHONE, ENVIRONMENT, and WORDS menus.

9) TIME CONTROL - This menu allows the user to perform any of the environmental control functions at pre-designated times. Each environmental control action in this menu will be performed at the specified times each day until deleted from the menu by the user.

The system prototypes are tested periodically by quadriplegics living in the dormitory area which is housed in the Biomedical Engineering Research, Development, and Training Center (RERDTC) which also contains the Biomedical Engineering Department. Quantitative information on the success of the system is obtained by recording each of the user's responses as well as the time of day (to the nearest 1/60 of a second) on a floppy disk. Later analysis of this data has demonstrated the success of the system (i.e., the frequent usage of the routine to alter the PHONE menu) as well as provided additional information which the designers have used for improvements.

The users' proximity to the research and development labs provides direct interaction between them and the researchers, allowing faster turn-around times for system alterations. For example, the first time the system was tested overnight, the student using the system complained that the blinking cursor for row/column scanning on the computer's CRT screen prevented him from going to sleep. The software was corrected, allowing for an automatic blanking of information on the screen when the system is inactive for more than two minutes. The altered software was given to the student by the end of that day, and system testing continued.

Additional Applications

The potential of the system for applications beyond independent living and communication for the severely handicapped is currently being explored. The use of the system in a hospital for the special needs of "functionally disabled" individuals such as those suffering from progressive or regressive nerve disorders is described by Chesson and Schubert (4). The usage of the system for employment purposes has also been successful. Currently, a post-polio quadriplegic has been provided with a computer system incorporating complete accounting software as well as ADAPTER. Additional software was developed to multitask the two software packages as recommended by Vanderheiden (12,13). Multitasking allows the computer to store two or more programs simultaneously in memory, thereby allowing the user to switch back and forth between programs without first having to access a secondary memory storage device such as a floppy disk drive. The multitasking software allows the client to alternate between execution of ADAPTER and the accounting package with two keystrokes. The client can therefore quickly respond to telephone calls using the ADAPTER software without altering the status of the business software and files.

RESULTS AND DISCUSSION

As an example of the information gained by storing a user's selections on floppy disks for later analysis, the results from a three week clinical trial of a single prototype system are presented in Tables 1 and 2. A detailed explanation of the significance of the results is presented by Cronk and Schubert (5).

	Week			Relative
Selection	1	2	3	Freq. (%)
SYS	98	75	50	46
MODE	1	3	3	1
ENVIRONMENT	29	28	26	17
PHONE	56	27	25	23
LETTERS	22	9	3	7
WORDS	16	7	2	5
Weekly totals:	222	149	109	99

Table 1. Results of Three Week Clinical Trial of Prototype GPI - Menu Name Selections

	Week			Relative
Selection	1	2	3	Freq. (%)
letters selected	-	90	81	22
words selected	2	0	0	1
phone calls	15	19	28	8
SAVE/DELETE (PHONE)	39	7	10	7
devices on/off	112	62	7	32
other	141	53	41	30
Weekly totals:	309	231	235	99

Table 2. Results of Three Week Clinical Trial of Prototype GPI - Command and Communication Selections

Briefly, the data illustrates the success of the system in its present form. For example, the user activated the device on/off functions (in ENVIRONMENT) 112 times the first week. Further examination of the data listings showed that he would turn devices on and off successively, indicating satisfaction with the system. It was also significant that the user felt comfortable with the SAVE/DELETE commands to alter his PHONE menu (at the time of the trial the only menu which could be altered). In earlier testing, the user had difficulty following the instructions for each step printed on the CRT. The program was then modified and the instructions amplified for clarity before this particular clinical trial.

CONCLUSIONS

1) The system in its present state is a very

functional independent living system.

2) The present method of storing selection data will prove instrumental in analyzing future system changes and will promote user friendliness.

3) Each system should be provided with sufficient secondary memory storage to allow the user to use other desired software in addition to the GPI. The floppy disk drive seems the only reasonable solution presently available.

4) Each user should have a custom-made system created from commercially available hardware and custom software to meet his own needs. If each individual who desires a GPI is tested to determine his abilities and needs, appropriate menus and selection techniques could be drawn from a pool of in-house routines so that each system would be optimized.

5) The program should be divided into smaller segments which can be individually accessed from the disk. This will permit less expensive computers with smaller amounts of memory to be used. For example, a Commodore VIC-20 with an 8k memory expansion cartridge ($250) could replace the PET 2001 computer ($1200).

6) The system should include an RS-232 communication link. Computer networks such as the Source and Compuserve are becoming increasingly important in information transfer, and handicapped persons should be given equal opportunity to access these networks as a step toward gainful employment.

7) Each user should be provided with a radio-linked keyboard and/or switch mounted on his wheelchair, allowing him to interact with the GPI even when not in direct visual contact with the system.

8) Bank-switching between various parts of memory is viewed as an alternative to the multitasking method described in this report. The Commodore P128 provides for such switching.

ACKNOWLEDGMENTS

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REFERENCES

1. Bowjanowski, T., Bloch, P., and Milner, M., "A Microprocessor Environmental Controller for Quadriplegics," Proceedings - Fifth Annual Conference on Systems and Devices for the Disabled, pp. 183-186, 1978.

2. Brown, Benjamin E., and Gregg Vanderheiden, "Considerations in the Application of Microprocessor Technology to Human Needs", Proceedings of the National Electronics Conference, 1978.

3. Byte, Vol. 7, September 1982.

4. Chesson, A. and R.W. Schubert, "Microprocessors in the Hospital - Communication for the Acutely Disabled", Proceedings of the 1st Southern Biomedical Engineering Conference, Shreveport, La., pp. 40-43, 1982.

5. Cronk, S.R., and R.W. Schubert, "An Adaptive Computer-Aided Independent Living System for Severely Handicapped", Proceedings of the 1st Southern Biomedical Engineering Conference, Shreveport, La., pp. 337-340, 1982.

6. Cronk, S. and R. W. Schubert, "A General Purpose Interface (GPI) for Independent Living", Proceedings of the 33rd Annual Conference on Engineering in Medicine and Biology (ACEMB), Washington, D.C., p. 209, 1980.

7. IEEE Computer, January 1981.

8. Proceedings of the Johns Hopkins First National Search for Applications of Personal Computing to Aid the Handicapped, October 1981.

9. Schubert, R.W., W.W. Moore, and S.R. Cronk, "Towards Employment of the Severely Handicapped", Proceedings of the 1st Southern Biomedical Engineering Conference, Shreveport, La., pp. 44-47, 1982.

10. Sell, G., Stratford, C., Zimmerman, M., Youdin, M., and Milner, D., "Environmental and Typewriter Control Systems for High Level Quadriplegics: Evaluation and Prescription," Archives of Physical Medicine and Rehabilation, Vol. 60, June 1979.

11. Stratford, C., Zimmerman, M., Youdin, M., Milner, D., and Sell, G., "Environmental and Typewriter Control Systems for Use by High Level Quads: the Suitability of Various Aspects as Determined Through Evaluation," Proceedings - Fifth Annual Conference on Systems and Devices for the Disabled, 1978.

12. Vanderheiden, Gregg, "Computers Can Play a Dual Role for Disabled Individuals", Byte, Vol. 7, pp. 136-162, 1982.

13. Vanderheiden, G., "Practical Applications of Microcomputers to Aid the Handicapped," IEEE Computer, January 1981.

Biomedical Engineering Department
Louisiana Tech University
P. O. Box 10348
Ruston, Louisiana 71272

1.10P

PROGRAMMER TRAINING FOR SEVERELY DISABLED INDIVIDUALS

C. Gerald Warren, M.P.A.   Thomas Stone, B.Sc.M.E., P.E.

C. Gerald Warren & Associates

HISTORY:

In the early 1970's, the Rehabilitation Services Administration (RSA) joined with the IBM Corporation to pilot one of the first formal "Projects with Industry" (PWI). It was recognized, particularly by IBM, that computer programming is an excellent vocation for disabled individuals because it is a profession where intellectual capacity is far more important than physical dexterity and mobility. In addition computer programming is an ubiquitous profession that is used by all major industries in all locations. It provided an excellent opportunity for severely disabled persons to enter into a well-paying profession which has good growth opportunities and excellent potential for good salaries needed to maintain ancillary needs. Thus the original computer programmer training project has grown to as many as 24 projects throughout the United States. Each is slightly different based on its regional organization; however, in general they have similar characteristics. They are sponsored, funded and administered by local agencies which may be State Rehabilitation Departments, independent rehabilitation facilities, community colleges, state universities or private nonprofit corporations. Secondly, most have a Business Advisory Council (BAC) who act as the advisors and guiding body of the project, establishing the nature and quality of the program. Finally, this BAC shares the responsibility with the sponsoring agencies to place the graduates in competitive employment.

IBM's involvement emanates from its Federal Systems Division project to train the disabled. Staff members of this project act as the catalyst in establishing new regional projects. They use their previous experience to assist regional project directors in establishing training locations, cooperative agencies, initial project organization, and most importantly making the necessary contacts to establish the embryo of a BAC. This council is made up of the executive or data processing managers or programmers from the major corporations in the region who are heavily involved in data processing as part of their companies' operations. Once established, this council is organized into committees which perform the 4 or 5 major functions necessary to establish the program. They assist in hiring the instructors, selecting the students, establishing curriculum which usually fills a 9- to 10-month period, including 6 to 8 weeks of internship. The BAC becomes active in evaluation and technical review of the students' progress and the course content. Later in the project the placement committee is established and helps train the students in job search and retention skills and also assists in placement.

The responsibility for provisions necessary for a disabled individual to participate in the project are assumed by the State Rehabilitation Agency and coordinated through the project director. This responsibility includes various phases of rehabilitation which may require evaluation of activities of daily living, transportation needs, the ability to perform classroom tasks as well as appropriate interfacing to the data processing equipment. This aspect then becomes a major challenge in order to assure that with the technical training the individual is going to meet normal work standards and compete realistically in the job market. To date this program has been extremely successful in its placement, exceeding 85%.

"Project Entry" began in Seattle in early 1982 when a private nonprofit corporation, the Resource Center for the Handicapped, the Washington State Division of Vocational Rehabilitation, and members of the University of Washington Department of Rehabilitation Medicine met with a representative of the IBM project to train the disabled. A Business Advisory Committee of some 20 major corporations in the greater Seattle area was established and the first class of 18 students was enrolled in January of 1983. The project was established within the facilities of the Resource Center for the Handicapped, which is a retired elementary school with exceptionally good classroom facilities and ample space in which to install the necessary equipment. The equipment being used is Bell System, Data Speed 4540 terminal, which is a general purpose display-based terminal system with a generic 3270 compatible display station. It utilized a cluster controller which allows attachment of 8, 16 or 32 devices including printers, keyboards and screens. The terminal system is connected by 2400 BPS private line to two sites, where main frame time is being donated by corporate members of the Business Advisory Council.

ROLE OF REHABILITATION ENGINEERING:

The success of such training programs is highly dependent on the students being able to physically accomplish all tasks necessary to perform classroom and keyboarding activities, and ultimately to enter the workplace physically capable of performing tasks that make them competitive in the job market. The rigorous student selection to "Project Entry" was not limited in any way by lack of physical ability because of the regional availability of technical services to perform adaptation of the classroom and workplace. Thus the disabilities of people range from those students who have no physical limitation, other than mobility, to those who have significant impairment in physical capability, i.e., persons who are C-4 quadraplegic. Students in the project in most cases are graduates from comprehensive rehabilitation programs and are being followed by vocational rehabilitation counselors.

The demands placed on the students when entering such a training project often require re-evaluation of their general rehabilitation status. Particular attention needs to be given to the equipment they have, and that which is required to maintain them in the program to assure them the ability to accomplish all the tasks involved. Many students are not accustomed to the physical demands and the limited musculature available makes it difficult to perform tasks over prolonged periods of time without fatigue, which certainly could interfere with their concentration, technical ability and general productivity.

Dealing with the issues of environmental adaptation may best be accomplished in two phases: first by establishing those steps necessary to allow the individual to participate in the course and to demonstrate his/her achievement and ability to succeed; then, once the bench marks are reached that indicate the ability to succeed technically in the workplace, there is good justification to pursue the more complex and expensive methods that will make these people efficient and competitive in that job market.

At enrollment evaluations of each client are performed to determine what the level of task accomplishment currently is; i.e., paper and book handling, writing, and rates of keyboard entry in strokes or words per minute. From this evaluation recommendations are made on what modifications to the classroom and terminal area would be required for the individual to demonstrate his capability. In addition, a list of all the possible options for equipment that would make him efficient and competitive in the workplace is developed to advise the counselor on what may be ahead and to give the student some notion of what potential he/she may have. The written evaluation and recommendations are discussed with the students, instructors and the vocational rehabilitation counselors and the classroom terminal adaptations are then implemented.

Aside from individual adaptations such as hand splints, templates, reading aids, mouthsticks and holders, and book holders, two major problems arise: posture and keyboard location. For those people with the loss of trunk musculature, just placing the keyboard on an elevated desk presents a problem of balance when they lift their arms to use the keyboard. Trying to support this posture produces excessive fatigue. Such keyboard location in most cases requires all motion for key entry to be generated from the shoulder. Many individuals referred to fatigue and pain in residual muscles when prolonged activity at a typewriter had been performed in the past. To achieve appropriate keyboarding function over prolonged periods of time, a posture must be established which allows the individual to use as little residual musculature as possible to maintain body balance, and the keyboard needs to be located in a position where small muscle movement can be used for keyboard entry. Those persons who during their training perform keyboarding using a mouthstick also need the keyboard located in specific areas where the shortest, lightest mouthstick can be used with the least amount of head motion. Thirteen of the 18 individuals involved in the program needed keyboard relocation and posture control for them to achieve minimal keyboard entry rates of 15 to 20 words per minute and to spend sufficient time on the keyboard without excessive fatigue.

Early in the project development it was agreed that entering the job market using a mouthstick and/or excessively complex mechanical systems for keyboard entry is not desirable. Therefore, keyboard substitutes were considered such as those that are often provided for personal computer interface, and extensive efforts were placed into interfacing this equipment to make it main frame compatible. Through donation or purchase the project has acquired several keyboard simulators which are interfaced to allow individuals to experience the use of Morse code entry, optical light pointers, row/column scanning and miniaturized direct select keyboards. These systems are made available to individuals to "test drive" them and to establish what form of keyboard substitution might best suite their needs and increase their efficiency. Those systems with large addressable memory are most desirable as major portions of a programming language can be installed in them, then used to construct programs with whole commands, words or phrases. Additional options for workplace adaptation are also discussed and considered, such as environmental control systems, automatic telephone dialing equipment, dictation equipment and other options that these individuals might need to perform tasks on the job.

METHODS:

In evaluating the major problem of keyboard location, the need to design a very flexible mechanism which would serve the needs of many different individuals within the terminal setting was identified. Because there were 18 students and only 8 terminals, the scheduling of their use required a good deal of flexibility in order to accommodate the varied needs of the students. Therefore, the mechanism holding the terminal for those who required relocation needed to be easily moved with almost infinite adjustability and able to put the keyboard anywhere within approximately 1-1/2 cubic feet. The objective was to do this inexpensively and with existing and available hardware. The design shown in Figure 1 illustrates the use of a photo tripod adapted to perform this function. The feet of the tripod are mounted on ball joints, the entire system when mounted horizontally then allows easy displacement of the tripod head to which the keyboard is mounted. By loosening the legs the mounting can be either extended or contracted, placed at various heights and lateral locations. The fine adjustment of the tripod head is used to extend the keyboard or for tilting and rotating it in three axes. Some modification of the locking mechanism on the tripod legs is necessary for them to sustain the load of the 11-pound keyboard. The locators are adjusted by the instructors or assistants in the course and provide all students comfortable access to the keyboards.

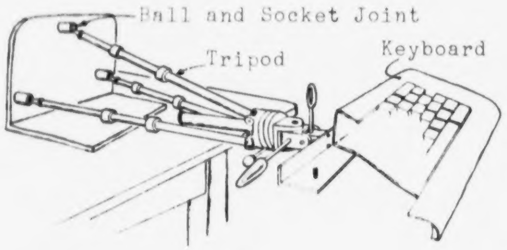

Fig. 1

Posture control for most of the individuals with loss of trunk musculature may ultimately require that they have some form of reclining mechanism on their wheelchairs; however, in the early phases of classroom activity, merely providing them with small ramps which elevate the front casters of the wheelchairs approximately 3-1/2 inches tilts the chair backward enough to vertically align body segments and allow time to assume a posture that is exceedingly comfortable over prolonged periods of time.

The second phase of this program begins when the point in the course is reached where there is little doubt about the student's ability to become a computer programmer. At that point further evaluation of the equipment necessary for the individual to achieve in the workplace will be made. The student will have a clearer picture of his/her needs and the vocational counselor will have complete justification to expend the funds necessary to advance the individual into more sophisticated equipment that will assure him/her of a competitive role in the workplace.

C. Gerald Warren
4825 Stanford N.E.
Seattle, WA 98105

THE DATA ROUTING MODULE: ACCESSING COMPUTER SYSTEMS WITH COMMUNICATION AIDS

2.1

Barry L. Rodgers
David P. Kelso
Gregg C. Vanderheiden
TRACE R&D Center - University of Wisconsin-Madison

ABSTRACT

Past techniques allowing people with physical handicaps to access computer systems required modification of the terminal hardware and computer software. This required computer expertise and was expensive. Now an inexpensive, totally transparent and easy to install module allows physically handicapped people to use communication aids as alternate input or output devices with computer systems that use standard RS-232-C[1] terminals.

The Data Routing Module is a small box plugged into the cable between the terminal and the computer. Once the Data Routing Module is connected any communication aid with an RS-232-C output plugged to the Data Routing Module can act as an alternate input or output device without interfering with normal operation of the terminal and without requiring changes in hardware or computer software.

INTRODUCTION

Computers are becoming integral components of all aspects of education, employment, and daily life. This is especially significant for persons with physical disabilities, whose greatest opportunities for meaningful employment may lie in jobs that require a lot of interaction with computers. Therefore, for the physically handicapped persons who can not operate a standard computer keyboard it is necessary to develop an inexpensive method to interface communication aids to computer systems. To accomplish this the TRACE center is developing a module that plugs into the RS-232-C cable between a computer terminal and a computer. The Data Routing Module allows a person to use any aid that can output ASCII characters via the RS-232-C serial standard as an alternative keyboard to the one on the standard terminal. It also allows an alternate display device like a Braille screen to display what appears on the standard CRT screen.

The Data Routing Module routes data from the communication aid to the computer and to the terminal display. Data from the computer is sent to the terminal display and to the communication aid. Data from the terminal keyboard is sent to the computer and to the communication aid. This routing makes the aid transparent to the system. Our initial goals were to develop a device that:

1) would allow communication aids to act as alternate keyboards to the terminal.

2) could be installed without any modification to the terminal or operating system.

3) does not interfere with the normal operation of the terminal in any way.

4) would operate in full or half duplex mode.

5) could be sold inexpensively ($100 to $300).

FINAL SPECIFICATIONS

1. The Data Routing Module has three 25 pin D RS-232-C connectors.
   a. one female connector for the main computer
   b. one female connector for the terminal
   c. one female connector for alternate input devices (communication aids, etc.), or for alternate output devices (Braille displays, etc.), or for alternate devices with both input and output capability.

2. The Data Routing Module is designed so that in FULL DUPLEX data is routed:
   a) from the computer to both the terminal and the alternate device
   b) from the terminal to the computer
   c) from the alternate device to the computer

3. The Data Routing Module is designed so that in HALF DUPLEX data is routed:
   a) from the computer to both the terminal and the alternate device
   b) from the terminal to both the computer and the alternate device
   c) from the alternate device to both the computer and the terminal

4. The Data Routing Module allows the terminal to send and receive data from the main computer at all times whether or not a device is connected to the alternate device connector. This requires that the alternate connector assume a transparent state when not connected.

5. No hardware handshaking lines are implemented to the alternate device but all 25 RS-232-C lines are passed through from the computer connector to the terminal connector making the Data Routing Module completely transparent.

6. There is a provision for an optional SPST switch accessible on the top of the enclosure that selects either full or half duplex.

7. The Data Routing Module uses an active circuit with integrated circuit RS-232-C drivers (1488s) that have more than the minimum RS-232-C drive capability and handle baud rates up to 19200.

8. Power is provided from a standard UL approved direct plug-in transformer that can be obtained from either Zygo, Inc. or Prentke Romich Co.

9. There are 4 status Light Emitting Diodes (LEDs) one red and three green. The red LED indicates power. Each of the three green LEDs is associated with one of the three RS-232-C connectors. When an LED is on it indicates that an active RS-232-C device is properly connected to the input pin of the corresponding connector. The LED will blink continuously while data is being received on that pin.

10. The Data Routing Module is designed to be light and drop resistant. It measures 4.5" x 7.5" x 2.3" and weighs less than one pound. All three 25 pin D connectors and all of the LEDs are mounted directly on the circuit board.

DISCUSSION

Specifications 5 - 10 are elaborated below.

Specification 5: Hardware Handshaking
Most systems do not use hardware handshaking and of those that do there is no one standard protocol. Implementing just two hardware handshaking lines would double the amount of circuitry and implementing all the RS-232-C lines for handshaking would increase the complexity another 3 or 4 times. Therefore, hardware handshaking is not implemented for the alternate device connector. All 25 of the RS-232-C lines are connected between the computer connector and the terminal connector in order to implement any static status signals that may be present and necessary without active circuitry. This facilitates the ready condition without knowing how specific handshaking lines are being used in a particular system and makes the Data Routing Module completely "transparent".

Specification 6: Full and Half Duplex
Changing the Data Routing Module from full duplex to half duplex would require that a switch be added and an accessible switch would add to the cost significantly. 90% or more of the current systems use full duplex and as time goes on an even larger percentage will be full duplex. If the Data Routing Module were used on one system exclusively then it need be switched to the proper mode for that system only once; this could be done by the person who initially connected the Data Routing Module. Anyone who can plug in the 25 pin D connectors to install the Data Routing Module would be able to operate a standard switch so a special accessible switch would not be necessary. However, if the Data Routing Module were used with a modem and the handicapped user wished to communicate with different systems then s/he might need to switch modes and it would be necessary to make the switch accessible to the particular user.

The circuitry necessary to allow both full and half duplex is relatively inexpensive and since there are still a few situations where half duplex is necessary, it is included. However, the switch itself is optional. A custom switch can be added either by the manufacturer or by the user.

Specification 7: Passive VS Active Circuits
A commercially available device , the MS-3 Modem Splitter (available from the "Black Box Company" of Pittsburg, Pa and listed for $149 in their 1983 catalog), may work as a Data Routing Module in some situations, but it will not work for all situations because it is completely passive. It connects three RS-232-C connectors in parallel to one RS-232-C connector and includes diode isolation on the parallel output lines. Since the RS-232-C standard requires a driver to drive only one load and since in a Modem Splitter (used as a Data Routing Module) the driver would have to drive at least two loads it violates RS-232-C. Therefore, the MS-3 will not work with all systems but since it has no active circuitry it may be less expensive than an active circuit Data Routing Module.

Many typical IC drivers (such as 1488s) used on modern equipment can readily drive more than one load. As a result, many systems in actual use are already cheating on the RS-232-C standard by using multiple loads or longer cables that will only work with these "typical" drivers. Therefore, it is important for most Data Routing Modules to have "typical" drive capacity in order to work with these systems. In addition, if the aid (the alternate device) has minimum RS-232-C drive capability then an active Data Routing Module with a typical drive capability would be necessary to act as a signal booster as well as a Data Routing Module. Aids with minimum RS-232-C drive capability are common (some serial boards for Apple II computers). As a result, the Data Routing Module uses an active circuit design with RS-232-C drivers (1488s) that have typical drive capability.

Specification 8: Transformer Location
Power is provided by a transformer from a standard 120 v wall outlet. Serious consideration was given to locating the transformer in the enclosure in order to make the Data Routing Module self contained and easier to carry. The alternative is to use a UL approved direct plug-in transformer. Putting the transformer in the enclosure would have required that the entire Data Routing Module be approved by Underwriters Laboratories in order to be used in many clinical situations. UL approval would cost several thousand dollars initially and the manufacturer would have to continue to pay several hundred dollars each year to maintain UL status. In addition, the process of obtaining approval can be slow (from 6 months to several years). For these reasons and others, manufacturers contacted were very much against using an internal transformer. Therefore, a UL approved direct plug-in transformer is used for power.

We designed the Data Routing Module so that it will work with either the standard Zygo (Portland, Oregon) 12.5 v direct plug-in transformer or the Prentke Romich (Shreve, Ohio) 10 v Autocom direct plug-in transformer. This makes it easy for either company to manufacture the Data Routing Module. Because the power supply circuit is very tolerant of voltage variations the Data Routing Module can be inadvertently connected to any UL approved class 2 direct plug-in transformer (max voltage is 30 v rms) without damage to the unit or danger of fire. This is important since many UL approved direct plug-in transformers use the same connector and since they may have any voltage up to 30 v rms.

Specification 9: Human Factors/Status Lights
The Data Routing Module may be used in two different ways. Ideally there should be a Data Routing Module more or less permanently plugged into each terminal that the handicapped user needs to have access to. More likely, a handicapped user may occasionally have to take a Data Routing Module with her/him to access a remote terminal such as at a library. In this case the Data Routing Module will often be installed by inexperienced persons and it becomes very important to make installation appear to be and be as simple as possible in order

to make them willing to attempt it. In order to accomplish this we suggested the addition of three green lights, one for each connector, that would only light if the connector were properly inserted and the connected device's communication circuitry were on. In addition, each light would blink in an easily perceivable way when data was being received by the Data Routing Module from the device connected to the corresponding connector. We also suggested a red light that would light when the Data Routing Module was correctly plugged into a suitable direct plug-in transformer that was itself plugged into a live 120v AC outlet.

Because the Data Routing Module circuitry is relatively simple these lights could add significantly to the cost. When we pointed out that the retail cost for the Data Routing Module might be $150 without the lights and $225 with the lights (or some similar ratio) all of those polled including clinicians, outside computer experts, and members of COPH II said they thought the status lights would be worth the extra money. The reasons given include the following.
The status lights would:

1) help assure the person who connects the Data Routing Module that he/she is doing it successfully.

2) give the handicapped user confidence that they can find someone willing and able to connect them to a strange system.

3) provide immediate positive indication of a functional connection.

4) give the handicapped user an indication that the terminal connection and the computer connection that s/he can't see are still properly connected.

5) help identify systems where the terminal computer connections are consistantly miswired.

6) identify simple correctable problems such as a turned off outlet, loose connectors, bad cables, main computer down, or aid battery low.

7) help in explaining the nature and degree of a potential service problem over the phone to the manufacturer's service department in order to determine if the device should be sent back to the manufacturer for repair.

As a result, the Data Routing Module includes these status lights. Since a positive indication is desired to indicate a correct active connection the green LEDs were designed to be ON when the connection is good. However, this creates a problem in visibility because it is more difficult to perceive a normally ON light momentarily blinking OFF than one normally OFF that blinks ON. Also, at high baud rates (9600) it is always difficult to perceive the blinking that indicates data transmission. Therefore, to provide an easily perceivable, useful indication of data transmission the design uses a special circuit that makes the green lights blink about 4 times a second when data is received no matter what the baud rate is.

Specification 10: Human Factors/Mechanical

The fact that the Data Routing Module may sometimes have to be carried along and hooked up to an unfamiliar system places some further demands on the design. The enclosure is made of impact resistant plastic. This makes it lighter and more drop resistant than a metal enclosure and is less expensive. The Data Routing Module is relatively light weight compared to typical RS-232-C cables, so the connectors are located to provide the straightest cable run. The terminal connector and the computer connector were put on the back since these cables would normally lead off in that direction and the alternate connector was put on the front where the aid's cable can go straight in.

There are now available very inexpensive plastic circuit board mounted 25 pin D connectors that appear to be a rugged and inexpensive alternative to panel mounted metal connectors. Since using these connectors could save signficantly on the cost of the Data Routing Module (and other aids with a number of connectors) we decided to include them in our prototype design in order to test their ruggedness in an actual use. To save further on manufacturing costs all the LED status indicator lights were mounted on the board. The design requires only the direct plug-in transformer connector to be mounted directly to the enclosure.

CONCLUSION

The Data Routing Module appears to offer a simple, cost effective way for physically handicapped people to interface their communication aids to computer systems that use standard RS-232-C terminals. To test the actual viability of the Data Routing Module several prototypes are being placed with handicapped computer users for their evaluation. Prototypes are also being evaluated by the COPH II handicapped consumer group in Chicago, and by the Systems and Aids Clinic (California State University at Sacremento). Prentke Romich Co. (Shreve, Ohio) and Zygo, Inc. (Portland, Oregon), two prominent aid makers, are also evaluating prototypes for potential manufacture.

ACKNOWLEDGMENTS

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REFERENCES

1. EIA Standard, RS-232-C, August 1969, Electronic Industries Association, Engineering Department, 2001 Eye Street, N.W., Washington, D.C. 20006

Barry L. Rodgers, Research Engineer
TRACE Center
314 Waisman Center
1500 Highland Avenue
Madison, WI 53706

MICRODEC II - ANTICIPATORY COMPUTER INPUT AID

C. W. Heckathorne L. Leibowitz J. Strysik

Northwestern University Rehabilitation Engineering Program

ABSTRACT

A computer input aid is described which utilizes anticipatory text presentation and selection to facilitate access to the computer. The aid, called MicroDEC II, is configured as an optional upgrade of the commercially available MicroDEC environmental control unit and retains all of the device control features of the standard MicroDEC. The two switches of the MicroDEC unit are used to select characters and words presented on an auxiliary display. The contents of the display are determined by certain statistical features of American-English so as to anticipate the item to be selected. Presently developed for the Apple II, the MicroDEC II requires no software and minimal hardware modification to the computer and can be used with any software package written to accept input from the Apple's keyboard.

BACKGROUND

The objective of the MicroDEC II project was to develop an efficient computer interface for an individual whose physical impairment precludes use of conventional keyboards or alternative direct selection interface aids. The design was guided mainly by two principal criteria. The first was that minimal hardware and no software modifications of the host computer be required. This insures that commercial keyboard oriented software could be accessed without modification by the MicroDEC II user. The second principle was to improve the efficiency of text entry to the computer by taking advantage of known statistical properties of American-English. Because the MicroDEC II is operated with two switches, in a user-controlled scan and select technique, the order in which selections are presented greatly influences the efficiency of text generation.

To facilitate development of the interface aid and provide it with greater versatility, the design was based on the commercially available[1] MicroDEC environmental control unit (1). The MicroDEC, originally designed by our laboratory (2), is a two-switch-controlled microprocessor-based emulator of the BSR (or Sears) Home Control System as well as a telephone controller. In essence, numerals for selection of devices and names of functions to be performed are displayed sequentially by user prompting with one switch and selected with the second switch. To accomodate various user configurations, the MicroDEC can be programmed to some extent by the operator.

The MicroDEC itself is based on a custom single board microcomputer, thus upgrading to include the functions of a computer interface was largely a matter of incorporating new software. This did involve some relatively minor hardware changes including expansion of the EPROM program storage to 8K bytes and RAM variable storage to 2K bytes. Because the MicroDEC uses a large eight character LED display that is preferred when controlling devices from a distance but which is not adequate for displaying general text characters for computer input, an auxiliary two line by 40 character LCD display has been added.

Presently configured for the Apple II and II+, the MicroDEC II includes a keyboard multiplexor board which plugs into one of the peripheral slots of the Apple II. Output from the MicroDEC II and from the Apple's keyboard are routed through this board to the keyboard input of the Apple 's processor board so that both can be used independently or interactively. Connection of the Apple 's keyboard output and input cables to the multiplexor board constitute the only modifications to the computer.

IMPLEMENTATION

When used as a computer interface, characters, words and menus are displayed on the auxiliary LCD display of the MicroDEC II. One switch steps a cursor through the choices and the second switch selects the choice. Operation is divided into text generation, editing and control. The editor menu contains the cursor control and input buffer insertion/deletion operations of the Apple keyboard. The control menu contains the reset and repeat key operations in addition to a branch into text generation and a branch to access MicroDEC environmental control.

Text generation is divided into character selection and word selection. For character selection, letters or digits and symbols are presented as one 5-character row of a row-column matrix. A special preceding symbol is used to display the next sequential row, with wrap around. Six rows contain all letters or all digits and symbols. Each row is completed by a carriage return symbol and symbols to branch to other modes. A seventh row contains special symbols for shift, escape, control and locking/unlocking keys. The row of characters is displayed in the first line of the LCD display while the second line is used as a 40-character buffer. During word selection, both lines of the display are used to present groups of words from a dictionary.

Anticipatory Text Presentation

A major use of computers by people with physical impairments will likely be as a writing tool. To reduce the number of switch actions needed to select text, the MicroDEC II incorporates a combination of digram letter anticipation and dictionary-based word anticipation. In the former case, statistics of American-English are used to order letters in the character matrix based on their probability of following the last selected character. The more probable letters (including the "space") are presented in matrix positions requiring fewer scanning and input operations to select. Thus the interface program tries to anticipate, using digram probabilities, the next character to be selected. Tests with samples of American-English text generation have shown the average number of switch closures per letter to be 3.73 for anticipation based on digrams compared to 4.42 for monograms (single letter frequencies) and 6.13 for an alphabetic arrangement in the selection matrix (3).

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[1] Medical Equipment Distributors, Inc., Maywood, Illinois

Anticipatory letter selection was first proposed by Crochetiere et al of Tufts University (4). A digram-based scheme similar to the one used in MicroDEC II is described in greater detail by Heckathorne and Childress (5).

Using digram letter anticipation, individuals with near normal movement times are only able to build text at about 8 words/minute (3). This is in comparison to 20 words/minute for non-disabled typists generating non-transcription text, i.e. rough drafts, tables and letters (6).

Gibler undertook a study (7) to determine the effect of a two-part dictionary on text generating efficiency and rate. In his analyses, digram letter selection was used to initiate word selection. The dictionary included a core element of the first thousand most frequently used words, which began with a digram, from the Brown Corpus (8) and a learning element of 200 words. The core element was intended to provide those words used most frequently in American-English; whereas, the learning element retained words not in the core which were spelled as the text was generated. These latter words would, for the most part, be topical words bearing on the subject matter of the text and would likely be used several times within the total text.

The results indicated that word anticipation based on initial digram selection did improve efficiency by further reducing the average number of switch closures/letter by 24% compared to digram letter selection alone. The improvement in text generation rate for the subjects studied was not as great, on the order of 3% to 10%. The difference is due to the tradeoff between switch activation movement time and visual search time when using a scanning based aid (9). The subjects used by Gibler all had movement times on the order of finger tapping rates of nondisabled people.

Based on the results of Gibler's work, a dictionary was configured for the MicroDEC II.

Dictionary Criteria

The dictionary of the MicroDEC II is comprised of a core of 500 words from the Brown Corpus and a learning element that can hold, on average, 148 words. Gibler (7) has shown that decreasing the size of the core dictionary from 1000 to 500 words reduces the efficiency of text generation by only 4%, compared to the 24% increase when the 1000 word dictionary was added to digram letter selection alone. It has also been shown (9) that the reduction to 500 words has a negligible or positive effect on the text generation rate of individuals with near normal tapping movement times.

The core element is not strictly the first 500 most frequently used words that begin with a digram. The data provided by Kucera and Francis (8) for the Brown Corpus gives the total number of times a type, distinct word, occurred in 500 samples of text covering 15 genres with approximately 2000 words of continuous text per sample. The number of genres and samples in which the word appeared are also noted. A review of the first 1000 most frequently used words shows that a number of high-frequency words that appeared in relatively few samples are included in the first 500 most frequent words. These words, essentially topical because they are used very frequently in few samples of text, were removed and replaced with words having more general usage.

The order in which words are presented is not based solely on ranking by frequency, as was done in the original dictionary studies. Ranking is based on the product (from the Brown Corpus data) of the total number of occurrences and the number of samples in which the word appeared. Conceptually a joint probability, the probability of a word being used in all text samples times the probability that it appears in any one particular sample, this value gives a better indication of the relative useage of one word compared to another. The presentation order has significance because of its obvious effect on word selection efficiency.

The learning element is contained in a 1500 byte block of RAM which on average holds 148 words. Words are entered in the learning element when they are spelled following an unsucessful search of the fixed dictionary. Thereafter, the word is included with the dictionary display when its digram is selected. This procedure relieves the user of consciously storing new words for later retrieval. They are stored by spelling as part of the text generation sequence.

Because it is feasible to fill the learning dictionary during prolonged text generation, counters are used to keep track of the most recent session in which the word was used and how frequently. The oldest, least frequently used word is automatically discarded from a filled dictionary to accomodate a new word. Thus, the learning element can be kept pseudo-static for topical continuity during several text generating sessions, but remain responsive to changes in topic.

Anticipatory Programming

In addition to word processing, computer programming is of interest to many people for development of personal, educational or vocational programs. Word anticipation can also be used for the generally restricted vocabularies of programming languages. Words not in the core element, such as variables and subroutine names, would be contained in the learning element after their first use.

Initially, we will incorporate the commands for Applesoft BASIC and for Apple's Disk Operating System (DOS). The MicroDEC II user will set the interface into a programming mode to separate the programming and general text dictionaries. Selection of BASIC words and DOS commands will be begun with letter selection followed by guesses from the programming dictionary.

Though the syntactic and grammatic structure of American-English is too complex to effectively incorporate these rules into general anticipatory text production on a small computer, the restricted syntax and grammar of programming languages could be used to advantage. Such rules would make it possible to further constrain the choice of dictionary elements to be displayed, thus reducing the search time needed to make a choice.

Applesoft BASIC is not the only language implemented on the Apple, though it is very popular. Due to the number of languages, it would be difficult to develop an anticipatory scheme for each of them. However, it may be possible to develop a reasonable interactive procedure whereby the interface user can set up the MicroDEC II for a programming language by defining its vocabulary and structure.

An alternative scheme for interactive anticipatory text generation has been suggested by Witten et al (10). This scheme uses partial string matching to form a model of the text as it is being generated. The more text that is generated, the greater the statistical base from which predictions are made. The chief virtue of this approach is that a priori knowledge of the vocabulary or syntax is not required. It is, however, computationally intensive which may delay its technical implementation as part of a stand-alone input aid.

Witten et al's approach produces better results with texts having relatively constrained vocabularies and syntax than with texts of general English. In consideration of this, one possible implementation would be to use their method to anticipate a programming language and to use the dictionary scheme already described to anticipate general American-English text. Combining the two approaches may provide an effective way of dealing with the richness of American-English while providing efficient adaptability to a wide range of programming languages.

SUMMARY

The MicroDEC II offers a versatile, efficient alternative as a computer input aid for some people physically unable to use a keyboard or other direct selection aid. Basing letter and word selection on known statistical properties of American-English significantly improves the efficiency of producing general text for word processing. Incorporation of the device and telephone control features of the standard MicroDEC provides increased function for the user, independent of computer accessibility.

ACKNOWLEDGEMENT

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REFERENCES

1. Doubler, J.A., Strysik, J.S., and Heckathorne, C.W., "MicroDEC-Based Keyboard Emulator for the Apple II Computer", Proc. of the 4th Annual Conf. on Rehabilitation Engineering, Washington, D.C., 1981, pp. 137-139.
2. Gibler, C.D., Van Vorhis, R.L., Strysik, J.S., Heckathorne, C.W., Doubler, J.A., and Childress, D.S., "MicroDEC: A Microprocessor-Based Environmental Control System", Proc. of the Int. Conf. on Rehabilitation Engineering, Toronto, Ontario, 1980, pp. 33-35.
3. Rombola, G., and Childress, D.S., "Computer-Based Control and Communication System for Severely Disabled Persons", Proc. of the National Electronics Conf., 21, Chicago, 1977, pp. 362-366.
4. Crochetiere, W.J., Foulds, R.A., and Sterne, R.G., "Computer Aided Motor Communication", Proc. of the 1974 Conf. on Engineering Devices in Rehabilitation, Boston, 1974, pp. 1-5.
5. Heckathorne, C.W., and Childress, D.S., "An Integrated Computer System for Anticipatory Text Generation and Device Control by Individuals with Severe Motor Impairment", Proc. of the IEEE Computer Soc. Workshop on Computing to Aid the Handicapped, Charlottesville, 1982, pp. 17-23.
6. Foulds, R.A., "Communication Rates for Nonspeech Expression as a Function of Manual Tasks and Linguistic Constraints", Proc. of the Int. Conf. on Rehabilitation Engineering, Toronto, 1980, pp. 83-87.
7. Gibler, C.D., "Linguistic and Human Performance Considerations in the Design of an Anticipatory Communication Aid", Ph.D. dissertation, Northwestern University, 1981.
8. Kucera, H., and Francis, W.N., Computational Analysis of Present-Day American English. Providence: Brown University Press, 1967.
9. Gibler, C.D., and Childress, D.S., "Language Anticipation with a Computer Based Scanning Communication Aid", Proc. of the IEEE Computer Soc. Workshop on Computing to Aid the Handicapped, Charlottesville, 1982, pp. 11-16.
10. Witten, I.H., Cleary, J.G., Darragh, J.J., and Hill, D.R., "Reducing Keystroke Counts with a Predictive Computer Interface", Proc. of the IEEE Computer Soc. Workshop on Computing to Aid the Handicapped, Charlottesville, 1982, pp. 3-10.

ADDRESS

Northwestern University
Rehabilitation Engineering Program
345 E. Superior St., Room 1441
Chicago, Illinois 60611

MATRIX KEYBOARD INTERFACING WITH THE NATIONAL RESEARCH COUNCIL'S MOD KEYBOARD

L.W. Korba, P.J. Nelson, G.C. Park

National Research Council of Canada

ABSTRACT

Interfacing computers to the handicapped should provide the handicapped with full control over the target computer and allow him to use a variety of input means. This paper describes the technical solution to this problem as embodied in the NRC's MOD Keyboard.

INTRODUCTION

With the steady growth in the requirement of computers for the work place, the requirement of people skilled in their use has also increased. For the handicapped individual, this is a bit of a mixed blessing, for the computer can be programmed to provide a variety of input techniques to accommodate them, thus providing job opportunities, on the other hand, the cost of programming each target computer for the potential user is prohibitive. Keyboard emulation is the only viable aternative.

BACKGROUND

Many handicapped users have great difficulty entering data using a typewriter keyboard. Keyguards offer the obvious solution for some. However this just skirts the problem of an inappropriate interface for the user. In fact many handicapped users have difficulty enough controlling 1 to 5 switches rather than the 63 or so of the standard keyboard. An approach which essentially does away with the standard keyboard and offers a user a wide choice of input techniques is keyboard emulation. The keyboard emulator device replaces the keyboard, allowing the handicapped user to enter data using a character selection technique particularly suited to his handicap. The emulator generates the codes and signals required by the equipment being interfaced. Now the usr can employ specialized controls for entering data that will speed his data entry, without requiring changes to the target computer.

MATERIALS AND METHODS

The keyboard emulator device used for this application is called the MOD Keyboard 1,2. The Commodore VIC-20 computer is used as the controller for this application. It offers built-in provisions for a number of input/output facilities (CRT interface, analog and digital joystick input, RS232C port, light pen input and memory expansion bus). The MOD Keyboard device is embodied in a cartridge which plugs into the VIC's memory expansion bus. A photograph of the circuit board housed within the cartridge is shown in Figure 1. On the card there are the following: an 8K byte eraseable programable read only memory (EPROM), 4K bytes of battery backed-up CMOS read-write random access memory and a 6522 VIA integrated circuit. The EPROM is where the MOD keyboard operating system is stored. The 4K of RAM provides non-volatile memory for storage of user files for selection. Data may be stored in this RAM area without fear of loss when the VIC-20's power is turned off. This feature facilitates the development of "adaptive" selection programs. It is possible to create selection programs that monitor the data entered by the user and create a list of most often used words. These words may be saved within the RAM and later updated as new words are selected. The compiled files of words may be accessed to select any particular word. The VIA device is used to provide two extra bit parallel ports for control of special input/output devices. There is a card edge connector protruding from the back of the cartridge for this purpose.

There are several ways of interfacing computers to the outside world. Many microcomputers offer as options, serial and parallel interfaces for this purpose. However, in order to have full control over all the functions of the computer, interfacing directly with the computer by way of the keyboard connection assures the user of compatability with all software packages and may provide control over special function keys unique to the microcomputer (e.g. Reset on the Apple, and restore on the Commodore VIC-20). This is especially true for microcomputers whose operating systems do not provide for input to be redirected from devices other than the keyboard. In general data transferred from a keyboard to a computer (or terminal) falls into three main categories: serial , parallel and keyboard encoded by the microprocessor itself (3). A keyboard emulation device must be able to interface the potential target device in any of these three modes of operation. As well, the emulator must be able to support the variety of coding methods that may be used between the keyboard and target device (ASCII, EBCDIC, and special scan codes). A special type of parallel interface is one that is used for interfacing microcomputers whose keyboards are simply a set of keyswitches scanned by the computer itself. Normally the keyswitches are arranged in an X-Y matrix configuration. One configuration is illustrated in Figure 2. In this diagram the keyswitches are arranged in some order with rows and columns of the matrix being interconnected by different switches. The microprocessor scans the keyboard to determine which keyswitch is depressed. Once a key closure is detected, the row and column address of the switch position is converted to the code appropriate for that computer. The problem in terms of interfacing this type of keyboard lies in the implementation of a device that will provide the switch closure for the target device. An elegant solution to this problem involves the use of the crosspoint matrix switch developed for use in telephone switching equipment. One such device (MT8804 Mitel Semiconductor) provides a 4 x 8 array of addressable switches. A switch in a particular column may be opened or closed by appropriate addressing of the array. There is also a master reset line that will turn off all the array switches when that line is pulsed. Using three of these devices allows the connection of a 12 x 8 switch matrix. This size is adequate enough to accommodate a number of different microcomputers (e.g. Commodore PET -10X8, Commodore 64 -8x8, VIC-20 -8x8, Radio Shack TRS-80 -8x8 and Acorn Atom -6x10). Unfortunately for keys not a part of the keyboard matrix (e.g. Restore on the Commodore VIC-20 keyboard), a separate connection must be made. This is accomplished by using a CMOS bilateral switch (CD4066).

The card housing the matrix switch assembly plugs into the back of the MOD Keyboard cartridge and is controlled by the VIC-20 computer through the 6522 VIA integrated circuit in the MOD Keyboard cartridge. Interconnection of the matrix switch array to the target keyboard is made by way of cabling. A block diagram of the device is shown in Figure 3.

With the addition of the matrix switch array, the MOD Keyboard can be used to control several varieties of computers directly through their keyboard interfaces. The matrix switch array has been connected to a VIC-20 computer and controlled by an Apple II computer.

CONCLUSION

Conversion of the matrix switch array for operation by the VIC-20 computer is being implemented and connection procedures for a variety of computers investigated. The most difficult part of the procedure is the connection to the target keyboard itself. Due to the inexpensive construction of the computer itself, an easy connection to the keyboard lines is not always possible. Ideally the matrix switch array should be connected in parallel with the target keyboard so that it will remain functional. For most computers this connetion will require hard wiring of the crosspoint matrix switch to the computer's lines. As well, separate software routines for the MOD keyboard must be developed for each keyboard due to the variety of possible switch interconnections. Even with these difficulties, the MOD keyboard with the crosspoint matrix switch attachment is a unique way of interfacing an inexpensive computer to a handicapped individual and run all of that computer's standard software without alteration.

REFERENCES

1. Park, G.C. Nelson, P.J. and Crabtree, D. National Research Council of Canada's MOD Interface System. Proc. Workshop on Computing to Aid the Handicapped, Charlottesville, VA, Nov.4-6, 1982, pp.91-95.

2. Crabtree, D., Korba, L., Nelson, P.J., Park, G.C. Access to Computers and Other Systems for Physically Handicapped Persons: The Modular Solution. Dig. 9th Can. Med. & 1Biol. Eng. Conf., Fredericton, N.B., kAug.15-18, 1982. pp.69-70.

3. Rogers, B.L., Kelso, D.P. Vanderheiden, G.C., Design of Universal Keyboard Emulators, Proc. 5th Annual Conf. Rehab. Eng., Houseon, Tx., Aug. 22-26, 1982.

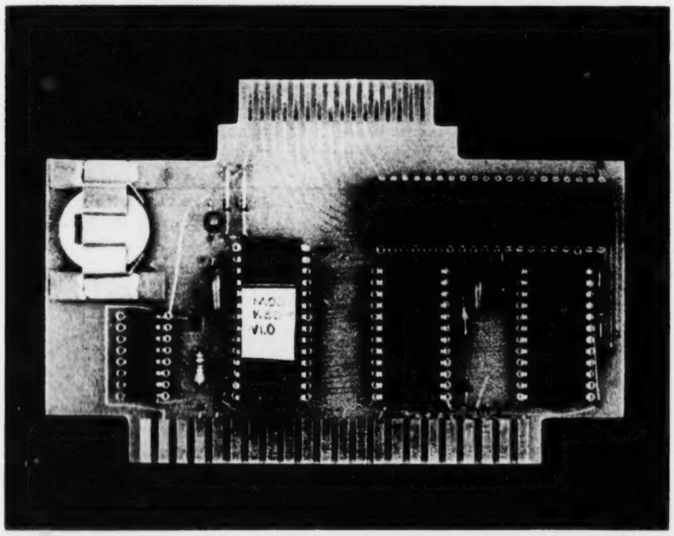
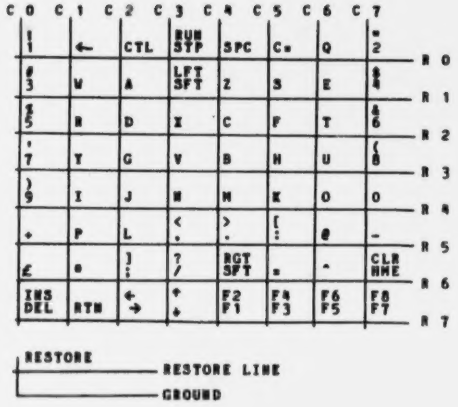


FIGURE 1. Photograph of the MOD cartridge with the case removed.


RESTORE
RESTORE LINE
GROUND

C0	C1	C2	C3	C4	C5	C6	C7	
! 1	←	CTL	RUN STP	SPC	C=	Q	" 2	R 0
# 3	W	A	LFT SFT	Z	S	E	$ 4	R 1
% 5	R	D	X	C	F	T	& 6	R 2
' 7	Y	G	V	B	H	U	(8	R 3
) 9	I	J	N	M	K	O	0	R 4
+	P	L	< ,	> .	[:	@	-	R 5
£	*	] ;	? /	RGT SFT	=	^	CLR HME	R 6
INS DEL	RTN	← →	↑ ↓	F2 F1	F4 F3	F6 F5	F8 F7	R 7

FIGURE 2. An example of a keyboard matrix switch arrangement (Commodore VIC-20).

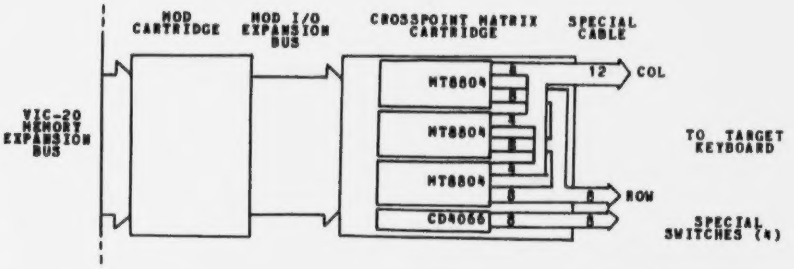

MOD CARTRIDGE
MOD I/O EXPANSION BUS
CROSSPOINT MATRIX CARTRIDGE
SPECIAL CABLE
VIC-20 MEMORY EXPANSION BUS
MT8804
MT8804
MT8804
CD4066
8
8
8
8
8
12
COL
8
ROW
8
8
TO TARGET KEYBOARD
SPECIAL SWITCHES (4)

FIGURE 3. Block diagram of the crosspoint switch matrix system as attached to the MOD keyboard.

National Research Council of Canada,
Medical Engineering Section,
Ottawa, Ontario, Canada. K1A 0R8

A.P.T.S.: A MICROPROCESSOR-BASED TYPEWRITER SYSTEM FOR THE PARTIALLY SIGHTED

Douglas R. Brent, General Manager, Apollo Electronic Visual Aids

Scott N. Smith, Senior Engineer, Apollo Electronic Visual Aids

ABSTRACT

This paper describes the evolution, specification and development of a typewriter system designed for partially sighted people. Primary emphasis is placed on those elements of typing for which partially sighted people require special features and how those features are implemented in this new typewriter system.

INTRODUCTION

Apollo Electronic Visual Aids has been in the business of designing, manufacturing, and marketing closed circuit television (CCTV) visual aids for over thirteen years. The properties, advantages and disadvantages of these CCTV aids are well known and have been widely discussed (1).

CCTV aids are adaptive aids. Although the primary use of CCTV aids is reading and writing text, they can be and are used for a variety of other vision-related tasks, e.g. viewing a blackboard, soldering, or even applying eye makeup. Over the years, a primary vocational use of CCTV aids has been for typing.

As adaptive aids, CCTV aids offer the partially sighted user a number of advantages. For example, the skills acquired in using the CCTV aid can be applied to a variety of different tasks. Further, the cost of a CCTV aid can be amortized over a number of different tasks. However, CCTV aids do not adapt equally well to all tasks.

Recognizing that typing is an important skill and that modern typewriters are not readily adaptable to CCTV aid assistance, Apollo has developed a typewriter specifically designed for partially sighted people. This device, the Apollo Professional Typing System (A.P.T.S.), includes the features of the most modern typewriters in a system meeting the needs of partially sighted typewriter users.

BACKGROUND

As noted above, aids have been used to assist with typing for over a decade. The camera is pointed (either directly or by use of a mirror) at the key strike area of a typewriter. The image displayed on the aid's monitor allows the partially sighted person to see the neighborhood of what is being typed.

This viewing methodology is quite workable for moving-carriage typewriters, but does not work nearly as well for fixed-carriage typewriters. A moving-carriage typewriter has a fixed key strike area. A fixed-carriage typewriter has a moving key strike area. All modern electric and the even newer electronic typewriters have fixed carriages. Further, the newest electronic typewriters have many editing features not previously available.

In early 1981, Apollo began a significant product development effort aimed at making modern typewriter technology available to partially sighted people. After examining a number of alternatives which included enhancing CCTV aids and modifying standard office typewriters, we decided that it made sense to design a completely new typewriter, or more precisely, a typewriting system.

PROJECT SPECIFICATION

The specification of A.P.T.S relied on analysis of the vision-dependent aspects of typing, current typewriter state-of-the art, and the needs of partially sighted people using a typewriter in the work place.

Vision-dependent aspects of typing

Interestingly, the act of typing itself is not at all vision dependent. Neophyte typists spend many hours learning that they can type faster and more accurately by not using their vision.

The primary goal of typing is to produce high quality, professional looking typewritten output. The most important vision-dependent factors for producing high quality output are page formatting and text editing.

Page formatting involves setting a left, right, top and bottom page margin. It also involves inserting the paper straight and to a particular position. Further, formatting might involve setting tabs, line skipping, etc. On a standard typewriter, all of these formatting features rely on vision.

Editing means the abilitv to make corrections of typographical errors. It also means the ability to make editorial revisions. An editing capability also requires the ability to determine current location on the page, where one left off typing, etc. Again, all editing features rely on vision.

Current typewriter technology

Typewriters have evolved over almost one hundred years to be very efficient machines for producing high quality text output. (Ignoring here the superiority of word processors for "typing" long documents and the ongoing controversy concerning keyboard design). Every typewriter has tab, margin and line spacing settings. Further, all typewriters have a shift lock key and underline capability.

Modern electronic typewriters have additional features. These new features have yet to become standardized, but they include lift-off style self correction, automatic carriage return at right margin, one line of memory, and many more. In defining A.P.T.S., we attempted to select the most useful of these features, without making the system difficult to use.

Other needs

In a vocational setting, it is rare that someone only types. Even in typing, it is commonly necessary to access ancillary materials such as a hand-written rough draft, a dictionary, a computer printout, etc. Any typing system for partially sighted people must be cognizant of their need for vision assistance in accessing these other materials.

Partially sighted people also have special ergonomic needs. The display itself needs to be magnified and should provide contrast enhancement. Finally, it is important that the individual be able to move close to the display medium, thus reducing the need for magnification.

Product specification

Taking into account these three major areas, the vision-dependent aspects of typing, current typewriter technology and other needs of partially sighted typewriter users, we specified a product according to these criterion.

PRODUCT IMPLEMENTATION

Components

A.P.T.S. is composed of two subsystems, a CCTV aid and a microcomputer-based electronic typewriter. The display of both subsystems is on a single 19" black and white monitor. The typing subsystem includes a keyboard, printer, and dedicated microcomputer. The microcomputer is a two board system containing a commercially available microcomputer board and an Apollo-proprietary video display board.

The CCTV aid subsystem may be either of two standard Apollo systems: the Imager Model 100 or the Imager Model 200. As noted above, these two systems are integrated, and their output displayed simultaneously on different sections of a single 19" monitor. The area of the monitor screen allocated to CCTV aid output vs. electronic typewriter output can be readily adjusted by turning a single knob.

Basic operation and structure

With an ordinary typewriter, one strikes a key, and the corresponding letter is printed on a sheet of paper. With A.P.T.S., one strikes a key, and the corresponding letter is electronically displayed on the monitor.

A.P.T.S. is a page oriented machine. A typewriter works by typing one page at a time. In a precisely analogous fashion, A.P.T.S. has an "electronic page" (buffer) onto which one types. The buffer can contain as many characters as would totally fill an 15" by 11½" piece of paper. This is 66 lines of 132 characters.

A.P.T.S. always ensures that there is a one-to-one correspondence between what the user sees on the display and what will be printed as final copy. If, for example, the user selects double spaced printed output, the internal page buffer shrinks from 66 lines to 33 lines. Selecting new left and right margin positions would similarly reduce the number of characters that could be typed on a line. Again, the "electronic page" operates as if it were a physical page, making A.P.T.S. easy to use and easy to understand.

At any time, the contents of the buffer may be printed by pressing a single PRINT key.

The Display

The A.P.T.S. display provides both magnification and contrast enhancement. Letters can be displayed in one of 16 sizes up to a maximum of about six inches high.

In addition to magnification, the display also allows for inter-character space stretching in both the horizontal and vertical direction. As much as full double spacing between letters and between lines can be selected. By providing for additional spacing between letters, it can be possible to utilize a lower magnification, thus enhancing reading speed.

Since the displayed letters are magnified, it will almost always be true that fewer letters are displayed on the screen (per line) than will appear on the final, printed output (per line). The user can scan through the page imagining the screen to be a window on the page. The entire screen can scroll both left-to-right and up-and-down. The view presented is much the same as a camera viewing a portion of a printed page as the page is moved beneath the camera. The user controls screen location by using cursor or "arrow" keys to move up, down, left and right.

To ensure that the user can always have a quick location reference, there are "go to the beginning of the document" and a "go to the end of the document" keys.

The Keyboard

A.P.T.S. has a 96 key keyboard with a numeric keypad and 20 special function keys. The keyboard is laid out in standard QWERTY order and has such important typewriter keys as Shift Lock, Alpha Lock, and Backspace. Both Shift Lock and Alpha Lock have red LED activation indicators.

All special functions such as magnification and editing functions are accessed by pressing a single key. There is no need for the typist to remove their hands from the keyboard.

Editing Features

Supported editing features are:

- o Single character correction - overwrite.
- o Character delete - delete and left fill.
- o Character insert - move right and insert.
- o Line delete - delete current line.
- o Line insert - move all lines down one line.
- o Line split - split current line into two new lines.
- o Line join - make two lines into one line.

For example, to delete a character, the user positions the cursor (an indicator of current position on the screen) at the character to be deleted. Pressing the Delete Character key causes that character to be deleted and each character to its right to be moved one position to the left.

To correct a single letter, the user positions the cursor over the erroneous letter and simply types the desired letter. The undesired letter will be erased and the new letter will appear on the screen.

With this powerful set of editing features, correcting a typed page is very easy. All editing features are accessed by pressing a function key.

The Printer

The A.P.T.S. printer is a specially selected and programmed high quality dot matrix printer. It provides two special features.

First, in addition to its normal-size typewriter character font, the printer can produce fifteen magnified type fonts, the largest being more than five inches tall. The printer also supports the same inter-character stretching features as the display.

A second important printer feature is that it has an automatic paper feeder. By simply pressing the paper towards the paper feeder, the paper is inserted correctly and in the same position every time.

The "single page" orientation of A.P.T.S. ensures that the printed page is an exact replication of the buffer memory. There are never dangling lines, and page formatting features such as margins, tabs, etc. ensure high quality of the final output.

Other typewriter functions

A.P.T.S. supports a number of other typewriter functions. These include margins, (left, right, top and bottom), tabs, and underlining. All of these parameters are set numerically through use of a menu. Numeric parameter setting gives the user complete control of the page format without relying on vision.

Another implemented typewriter function is Automatic Carriage Return. The last complete word typed across the right hand margin boundary is erased and then moved to the beginning of the next line. The user can type continuously without ever having to hit the Return key.

A final typewriter function worthy of note is its non-volatile memory. As noted above, typewriter settings such as margins and tabs are set using a menu. All such parameters, including display magnification can be stored in non-volatile memory. The next time the user turns on the machine, it will be set to the appropriate magnification, and all tab, margin, etc. settings will be intact.

CONCLUSION

A shift in typewriting technology necessitated the development of new ways for partially sighted people to access the most modern typewriting technology. Apollo invested two years of intensive product development in this task, the result of which was A.P.T.S.

This product development effort has resulted in what we believe is an important vocational product. A.P.T.S. has a number of important and unique features that make it a useful typing system for the partially sighted. However, perhaps equally important is that this type of product i.e. microprocessor-based, offers the hope of more rapid, useful and economical product innovation by Apollo and other manufacturers. The beneficiary of this effort will undoubtedly be the partially sighted consumer.

ACKNOWLEDGEMENTS

Much of the production engineering of this product was performed by Tim Wilster. Some of our initial research into large character display was done by a consultant, Richard Roose.

REFERENCES

1. Genensky, Sam, et. al., "A Closed Circuit TV System for the Visually Handicapped", Research Bulletin of the American Foundation for the Blind, June, 1969 pp. 191-204

Douglas R. Brent
Apollo Electronic Visual Aids
Box 2755
Chatsworth, California 91311
(800) 272-8083
(213) 700-2666 (in California)

IMPLEMENTATION OF AN UPGRADED COMPUTER SYSTEM FOR A ROBOTIC AID FOR THE SEVERELY DISABLED

Stefan J. Michalowski

Department of Mechanical Engineering
Stanford University

INTRODUCTION: THE ROBOTIC AID

The Robotic Aid project is an ongoing effort to harness state-of-the-art Robotics technology to serve the needs of the severely disabled. The work of our group is based on the premise that an industrial-grade robot can be adapted to allow a severely disabled user (quadriplegic) to manipulate objects in his/her immediate surroundings. Our goal is to develop a compact device that will form a natural part of the user's environment and can be used to perform basic manipulation tasks such as eating, drinking, turning pages in a book, using appliances, etc.

Viewed as a system, the Robotic Aid consists of three major components: (1) the human user, (2) the robotic arm and its sensors, (3) the supervisory computer which serves as an interface between (1) and (2).

The human user

The user performs the highest supervisory role by making the most important decisions as to which task is actually being performed. He/she interacts with the computer by entering voice commands to the speech recognition unit. The user moves the arm towards specific objects and selects trajectories for the motion of the arm by issuing a series of position and velocity commands such as "left", "right", "forward", "backward".

The lowest-level decisions, such as servoing the joints of the robotic arm, are undertaken by a computer system since they would represent an impossibly tedious and time-consuming burden to the human user.

The robotic arm and sensors

We have chosen to use a PUMA 260 robotic manipulator. It has six joints and is thus able to achieve any position and orientation of the end-effector (hand) within its reach of approximately 1.5 feet from its base. The electric motor on each joint is controlled by a dedicated microprocessor which continuously servos the joint to an angle downloaded by the main supervisory computer. The joint microprocessors expect to receive a new joint angle every 28 ms. (i.e. at a rate of 35 Hz.) which is the period of the Arm Controller clock and which, as will be described below, imposes a fundamental timing pattern for the supervisory computer. The arm, joint micros and Arm Controller clock are manufactured by Unimation, Inc.

We have equipped the robot with a sensate hand which is instrumented with optical proximity sensors. The output of these sensors can be converted to a distance from an object of known reflectivity and this information can be used in turn to influence the motion of the arm such as to center an object between the fingers of the hand or to prevent the hand from colliding with nearby objects. The translation of raw sensor readings to arm motions is carried out by a dedicated Z-80 microprocessor which sends its output to the main supervisory computer.

A force-sensing wrist has been built and its outputs will also be used to control the motion of the arm. At present, the supervisory computer receives raw data readings only from the wrist.

REQUIREMENTS FOR COMPUTER SYSTEM

The supervisory computer functions as an interface between the user and the arm. It accepts spoken commands and interprets them as a desired arm motion. It also gathers data from the sensors and combines all of this input information to determine the actual motion of the six joints. As was mentioned earlier, the computer operates under a fundamental time constraint: to produce a smooth arm motion, the new set of joint angles must be computed every 28 ms. This places a premium on performing calculations, especially floating-point ones, at high speed. At the same time, it is desirable to have a system which supports a high-level operating system and language and for which a good selection of peripheral devices is available. The cost (approximately 20K$) should be consistant with that of other components of the Robotic Aid.

The first version of the Robotic Aid, which is now undergoing a series of intensive evaluation trials at the VA Medical Center in Palo Alto, California, used a Zilog Z-80 based computer system. The fundamental structure of the control system was developed using this device. Limitations of speed, memory, word size, and reliability of the Z-80 based system made an upgrade desirable, allowing the group to develop new control schemes for moving the arm as well as providing a more powerful resource for the future implementation of new functions for the Robotic Aid such as automated grasping and force-controlled motion.

IMPLEMENTATION

Hardware and operating system

The new supervisory computer system is built around Digital Equipment Corporation's LSI11/23 microprocessor. This 16-bit machine has access to an 18-bit physical address space through the use of a Memory Management chip. We have configured our system to include a FPF11 Floating Point Processor option. The LSI11/23 processor, the memory and all of the peripheral devices are linked by a bus (Q-Bus). Many kinds of I/O devices which conform to the Q-Bus standard are available from a variety of manufacturers. Our system is equipped with hard disk drives for mass storage as well as serial and parallel I/O interfaces.

Digital Equipment Corp. provides a multi-task, multi-user operating system, RSX11M, and we have chosen to implement all of our software in the context of this system. It features convenient tools for program development: editors, compilers and various utility programs. More importantly, in view of the real-time control reqirements outlined earlier, it provides a software framework for interacting with I/O devices(through a software structurecalled a Device Driver) and for coordinating time-critical tasks such as initiating data acquisition and filtering of acquired data.

Data acquisition

Several external devices send data to the supervisory computer. Thirty five times a second, this data is used to determine a set of joint angles, thus generating the desired arm motion. The devices are of two kinds: those which provide input asynchronously (at unpredictable times and, in our case, at low rates) and those whose data must be acquired at the fundamental 35 Hz. rate. The speech recognition system is of the first kind since users cannot be expected to utter commands at more than 1 Hz. The second group of devices consists of the sensate hand, force-sensing wrist, six degree-of-freedom joystick and Unimation teachbox pendant. The PUMA 260, although primarily an output device, also belongs to this category. Each device transmits or accepts on the order of 10 bytes of data within each Arm Controller clock cycle. Given that we wish to dedicate as much CPU time as possible to performing the motion-determining computations described below, we have implemented a separate interrupt-driven Device Driver for each unit, such that the CPU interacts with each device only when that device is ready to transmit or receive data. When set up in this way the data acquisition process appears to operate as though all of the attached devices were interacting with the computer simultaneously (in parallel). In reality, of course, the individual data transfers are interleaved in time.

To synchronize the data acquisition with the 35 Hz. Arm Controller clock, a separate Driver, called the Dispatcher, was written. It receives interrupts at 4 times the fundamental frequency (i.e. at 140 Hz.). For each of the four subcycles, the Dispatcher can activate data acquisition from one or more of the external devices, each of which is then served by its own Driver. The Dispatcher can also activate software tasks which filter incoming data or perform motion computations.

The input data are stored by the Drivers in one large (2K words) block of memory. All of the software modules which make up the robotic control system can, if desired, have access to the contents of this memory area.

Computation of arm motion

At the beginning of each 28 ms. cycle, the configuration of the arm can be represented mathematically by a square matrix of the form:

$$T = \begin{matrix} Nx & Ox & Ax & Px \\ Ny & Oy & Ay & Py \\ Nz & Oz & Az & Pz \\ 0 & 0 & 0 & 1 \end{matrix}$$

In a Cartesian coordinate system which is fixed with respect to the stationary base of the manipulator, the vector $\overline{P}$ specifies the x, y, z coordinates of a point at the base of the robotic hand. The vectors $\overline{N}$, $\overline{O}$, $\overline{A}$ specify the orientation of the of the hand in the fixed system.

During the cycle, the Dispatcher activates a process which, given T and taking into account the latest sensor inputs and the user's spoken commands, calculates a new configuration T' .

We have chosen to describe the motion of the arm with respect to any Cartesian coordinate system (not necessarily the fixed one) in terms of a velocity vector (Vx, Vy, Vz, Ux, Uy, Uz) where Vx, Vy, Vz represent the translational velocities of the base of the hand along the x,y,z axes and Ux, Uy, Uz are rotational velocities about the axes. Whenever the velocities are small (as is the case in our application), we can find simple linear equations which transform T into T' . Specifically, if we define a matrix D:

$$D = \begin{matrix} 1 & -Ux & Uy & Vx \\ Ux & 1 & -Ux & Vy \\ -Uy & Ux & 1 & Vz \\ 0 & 0 & 0 & 1 \end{matrix}$$

then the equations become particularly simple. For instance, if the velocity vector is defined with respect to the same fixed system as T, then $T' = DT$. In another case, when the velocity coordinate system is embedded in the moving hand, we have $T' = TD$. This last equation is the appropriate one for the sensate hand and the force-sensing wrist.

After each device's data has been used to transform T into T' , the joint angles which correspond to T' must be calculated. One of the members of the group (Buckley) has derived a set of nonlinear equations to do this.

As a final step, the Dispatcher activates a Device Driver which downloads the angles to the joint microprocessors. The fundamental cycle is now complete and the data acquisition process can begin anew. The above sequence of events forms the kernel of the computer's functions. All of the component procedures must be optimized in terms of efficiency and speed.

ONGOING PROJECTS

Evaluation studies have shown that the limited reach of the robotic arm degrades its usefulness for many tasks. We have therefore undertaken to mount the arm on an electrically driven vehicle. The added computational burden involved in controlling the vehicle's motion should be easily incorporated into the scheme described above.

A major area of activity in the group has to do with implementing intelligent grippers. Jameson is developing a hand equipped with tactile sensors and a dedicated microprocessor. It will appear to the supervisory computer as another input device and will, through its own Driver, contribute a velocity to the overall computation.

CONCLUSIONS

The control system for the Robotic Aid is being implemented on an upgraded computer system. Major portions of the software are already in place. The expanded power of the system should carry the research group through the next phase of development and should significantly enhance the usefulness of the Robotic Aid for disabled users.

ACKNOWLEDGMENTS

The system described in this paper is based in large measure on the first, Z-80 based, version of the Robotic Aid. Charles Buckley, Machiel van der Loos and Charles Wampler were responsible for developing that system. Wade Hennessy and John Walecka have worked on various software components of the new, LSI11 based, system.

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ADDRESS

Design Division
Department of Mechanical Engineering
Stanford University
Stanford, CA 94305

2.6 A Design/Development Methodology for Rehabilitation Devices Using Embedded Microcomputers

David L. Jaffe
Rehabilitation Research and Development Center
Palo Alto Veterans Administration Medical Center

ABSTRACT

In this paper, a strategy for the development of 'smart' rehabilitation devices will be presented. The use of standard, commercially available STD bus hardware is the key to producing products that can be efficiently designed and easily replicated, while an interactive Forth software environment enhances programmer productivity. The concept of Host/Target communication, which links the development computer system to the application hardware, completes this design methodology.

NEED

There is a class of rehabilitation devices that could benefit from the inclusion of a microcomputer. Products that require [1] an unusual user input, [2] a complex control algorithm, [3] a real-time display, or [4] that are dynamically programmable are good candidates for an embedded microcomputer. The user deals with such a device through specialized inputs and outputs rather than the keyboard, cassette recorder, disk drives, or CRT terminal of consumer microcomputer systems. An example would be a voice activated robotic aid in which vocal commands from the user are translated into movement instructions. The intricacies of the computer's operation need not be of concern to the user. In fact, from his/her point of view, the computer in such a device would function as invisibly as the giant computer network of the nationwide telephone system.

PROBLEM

The design and development of a microcomputer product is not an easy task. The rehabilitation research team must be concerned with both hardware and software issues. Another major problem is the interaction with the application hardware which uses a minimum amount of memory and development resources. The same system that performs invisibly for the user must be accessable to the designer during development. The application system must, in addition, be able to execute its software program quickly enough to provide real-time control.

SOLUTION

At The Palo Alto Veterans Administration Medical Center, Rehabilitation Research and Development Center, standardized hardware, software, and an efficient development strategy has been formulated for the construction of embedded microcomputer systems. Key elements of this process are listed below.

1. Industry standard STD computer boards are selected where possible (1). Although this may be more costly in price and space than building a custom board, it does assure the designer of a working piece of hardware. It also reduces the designing, wiring, testing, and debugging time necessary in building a board that performs identically. STD bus boards are commercially available and can provide almost any function; serial interface, parallel interface, memory, counter/timer, A/D, or D/A conversion. Their widespread availablity means that systems specifying these boards can be easily replicated.

2. The Forth language has proven to be a software system that is ideal for process control applications (2). It is a highly interactive, extensible, reverse Polish high-level language that runs on most microcomputers. The programmer builds her/his application in a bottom-up fashion, starting at the most elementary level, testing and debugging at each step. The major advantage of this procedure is that the designer can demonstrate to him/herself and others that the program in development will perform as expected. The resultant Forth application program typically runs faster than the comparable BASIC program and is easier to code than the assembly language equivalent.

3. The final element in this design methodology is the link between the development system and the application system. This is done in the following manner. Hardware communication is typically accomplished by a serial interface between the systems. During development, this connection is the pathway for Forth dialog, while during operation it serves as a serial maintenance link providing a means for parameter modification and trouble-shooting.

The software uses this link. The host Forth development system with its resources is used to edit, store, test, and debug the programmer's code. When fully tested, the program is sent over the link and compiled by the application's Forth kernel into its memory space. At this point the program can be tested on the application system, using the hardware that will comprise the final system. When thoroughly tested, the application program RAM memory image is transferred into EPROM storage. Then, upon power-up, the target system begins executing the application program, now in non-volatile memory.

REQUIREMENTS

The typical minimum hardware requirements for the host development system are a microcomputer system with disk storage, CRT terminal, and a serial communication link to the application system. The target system also requires a serial port, as well as EPROM memory to hold the Forth kernel, and memory that can be configured either as random access or non-volatile storage. Several commercially products are available that contain this functionality on a single board (3). Additional boards to support the desired application would complete the target system's complement of hardware. The version of Forth sold by Jib Ray supports the Host/Target scheme presented here (4).

Table 1 diagrams the relationship of the host and target sytems and their memory resources during both the development and rehabilitation use phases.

CONCLUSION

Products with embedded microcomputers can benefit individuals with disabilities by conveying their will to other devices or to other individuals. The methodology described in this paper provides the rehabilitation designer an efficient development strategy for these 'smart' devices.

REFERENCES

(1) The STD BUS Buyers Guide, Ironoak Company, Volume 1, Number 1, October, 1982.

(2) Leo Brodie, Starting Forth, Prentice Hall, 1981.

(3) DSTD-102 CPU with Serial I/O, dy-4 Systems Inc., Ottawa, Ont.

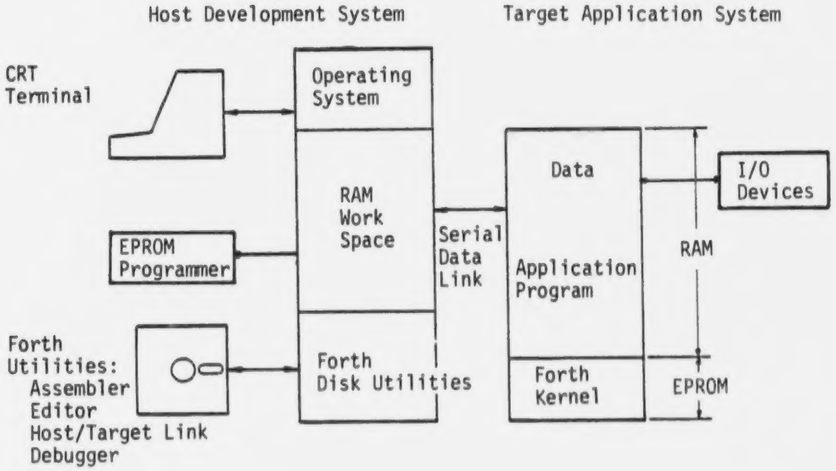
(4) Jib Ray Forth, 1114 La Vista Road, Santa Barbara, CA 93110.

ADDRESS

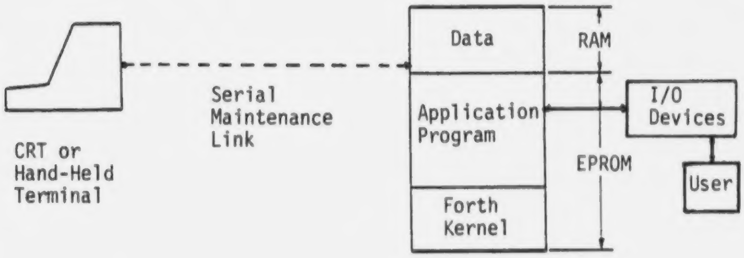
David L. Jaffe
Palo Alto Veterans Administration Medical Center
Rehabilitation Research and Development Center
3801 Miranda   Mail Stop 153
Palo Alto, CA 94304

Table 1 - Host/Target System Development

Development Cycle:


Host Development System
Target Application System
CRT
Terminal
Operating
System
RAM
Work
Space
EPROM
Programmer
Serial
Data
Link
Forth
Utilities:
Assembler
Editor
Host/Target Link
Debugger
Forth
Disk Utilities
Data
Application
Program
Forth
Kernel
I/O
Devices
RAM
EPROM

Running Application


Data
Application
Program
Forth
Kernel
RAM
EPROM
I/O
Devices
User
Serial
Maintenance
Link
CRT or
Hand-Held
Terminal

THE DEVELOPMENT OF MICROPROCESSOR BASED AIDS FOR THE HANDICAPPED

WARMAN, K., RASO, V.J.

Glenrose Provincial Hospital

ABSTRACT

Advances made in microprocessor technology have the potential to improve significantly the capabilities of almost any handicapped individual. This technology will have an impact in areas such as communication, medical safety, career education and environmental interaction. The potential cost benefit can easily reach $1,000,000. per year in Canada alone. The difficulty with many technical aids is that they require individual patient fitting. The Glenrose Hospital is the rehabilitation institution in Northern Alberta. Our aim in developing a Computer Based Technical Aids Program has been to design a system which provides flexibility not only in what it can do but also in what type of input is required by the user. The design consists of a Radio Shack colour computer adapted with plug compatible modules for speech synthesis, telephone access and environmental control. The interface consists of another Radio Shack colour computer that acts as a keyboard emulator and a scanning device used by the patient. The emulator and scanning board can be controlled by radio frequency. A protocol has been established and five patients have been selected for evaluation of this system. The next phase of this project will be to expand the input devices available, to incorporate the system onto an electric wheelchair and to expand the software available.

INTRODUCTION

It is estimated that as many as 500,000 people in the United States, and likely 50,000 people in Canada are unable to communicate either vocally or with standard sign language (1). In addition there are many more persons in institutions or group homes because of their physical limitations. Advances made in microprocessor technology have the potential to vastly increase the opportunities for improved communication and independent living for these people. Vanderheiden (2) cited the following areas in which microprocessor technology would have a significant impact:

a. communication aids;
b. aids to clarify sensory information;
c. remote manipulators or controllers;
d. aids to improve the proficiency of information transfer;
e. environmental control aids;
f. recreational aids,
g. information resource;
h. security and monitoring systems.

Advances made in these areas can be cost effective. It is estimated, in Canada, to cost more than $30,000. annually to care for institutionalized patients and approximately $8,000. annually to support handicapped individuals living independently (3). If 500 of those in institutions can be helped to live independently, then over a $1,000,000. per year will be saved.

Design Philosophy

The practical application of technical aids to the handicapped individual requires a high cost associated with adapting the aid to the abilities of the individual. In order to overcome this our aim has been to develop a standard control centre with a keyboard emulator. The interface between the emulator and the user is completely flexible. Other criteria established to aid in the design of the system are:

1. use available commercial hardware;
2. must accommodate commercial software;
3. system must be able to support a variety of input devices;
4. system must be able to support a variety of output devices;
5. must be possible to control the system remotely, e.g. with RF controllers; and
6. must be affordable for individuals.

The Control Centre

This system uses two functionally independent CPUs with the first one acting as an intelligent keyboard emulator for the second (FIG. 2). The emulator CPU is a 6809E, as used in a Radio Shack Colour computer. The second CPU can be any other microcomputer that is readily available (i.e. Apple, IBM, Radio Shack colour computer, etc.). The data bus for the second CPU has been expanded (using an 8255 programmable interface) to allow for up to 15 parallel I/O ports. Of these 15 I/O ports, three are used presently by a speech synthesizer, a phone interface and an RS-232 port switching board (to allow for more than one serial device to be connected at a time). Serial devices connected to the latter board include a printer and a module controller.Input to the system comes from an analog voltage transduced from whatever action is being used to drive the scanner (i.e. eyemovement, joystick). This signal is fed into an A/D coverter. The digital output is analyzed by software and then used to control the keyboard emulator/scanner.

A transmitter/receiver unit is used to provide radio frequency control. The transmitter is located with the control device used by the patient, while the receiver is placed on the scanner board. The radio frequency signal is modulated by the input device and then transmitted. The received signal is sent to the A/D converter and processing continues as defined earlier.

System Features

Presently the system features a directed scanning board (optional row-column scan) which can be expanded to virtually any size. Each scanner position acts as a programmable soft key, the function of which can be changed by the user. This provides an extremely large number of single function keys, increasing the speed with which the system can be accessed.

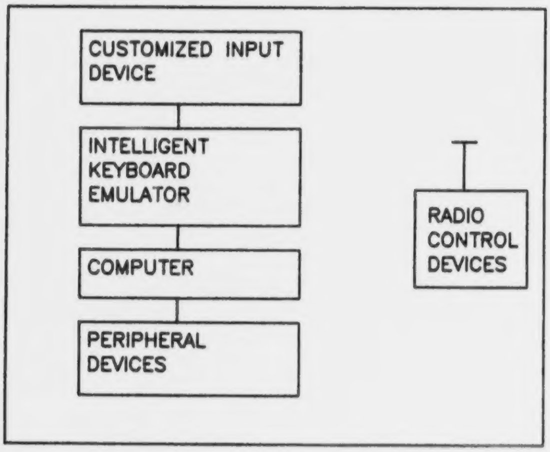


FIG 1. SYSTEM BLOCK DIAGRAM

Virtually any transducible force or physical property can be used to drive an input device. The input device parameters are changeable through software. The emulator board can be controlled by remote radio control input devices. Up to 256 input levels are discernible on any particular input device.

The system uses a keyboard emulator so that user accessibility to the main computer is not restricted by a resident program. Computer then controls a monitor, a printer, a phone, a speech synthesizer, a cassette and environmental control/sensors (FIG. 2). In addition there are 8 parallel ports which are expandable to 15. The system includes:

a. an unlimited vocabulary speech synthesizer;
b. a phone interface which allows for placing or receiving of calls through the computer (this can be done in combination with the voice synthesizer);
c. an attachment for a modum to enable the computer to communicate with other terminals and information systems;
d. remote control of up to 256 lights/ appliances each with programmable on/off times:
e. radio control input devices which allow greater mobility while using the system;
f. capability to store messages on cassette tape/printer/monitor;
g. by adding appropriate sensors, the system can monitor environmental/ physical parameters. This feature, when combined with the voice synthesizer/phone interface can provide security by automatically calling a predetermined phone number when the sensors indicate something is wrong.

Preliminary Patient Study Group

Preliminary studies are about to begin with 5 patients to evaluate this system. This initial group was chosen based on the following criteria:

1. a definite need for communication/environmental control aid;
2. must be medically stable;
3. must be in the educable range of intellectual function;
4. must be familiar with other communication devices;
5. must have parental or group home support;
6. must be a reliable user;
7. must be able to control an electric wheelchair-type joystick device.

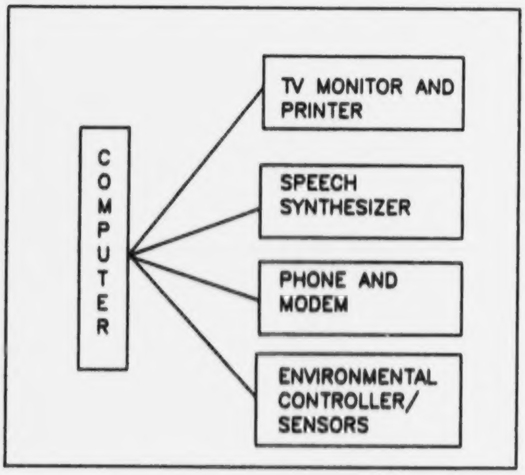


FIG 2. PERIPHERAL DEVICES

Each patient has a different set of goals that require slightly different software and hardware adaptations. It was decided that this particular group would use a joystick as a primary means of controlling the keyboard emulator. An Independent Living Suite within the hospital has been adapted to include environmental control modules. This acts as a model of the home so that patient needs and the limitations of the control system can be properly evaluated. A typical patient is Jason. Jason is a 16 year old with cerebral palsy (spastic quadriplegic). He has an electric wheelchair and communicates with a Handi-voice. Jason is finding it difficult to keep up in school because of difficulties he has in doing his homework. Our goals are very simple in this case: to develop a directed scan system to act as a keyboard emulator; to provide software that will allow Jason to do his homework on a television monitor and then either to store it on cassette tape for review by his parents or have it printed to handin to his teacher.

Future Direction

The experience gained with these 5 patients will form the basis for a revision of this system. Within this next system, we also wish to include a wider range of input devices such as touch plates, optical pointers, etc.. Another aim of the next version will be the ability to incoorporate it into an electric wheelchair. And of course, there is the ever present need for expanded software.

REFERENCES

1) BAKER, B. MINSPEAK, BYTE, 7, 9:186, Sept. 1982

2) VANDERHEIDEN, G. Computers Can Play A Dual Role For Disabled Individuals, BYTE, 7, 9:136, Sept. 1982

3) Independence Through Environmental Control Systems published by Canadian Rehabiliation Council for the Disabled.

Address Correspondence to:

J. Raso, P. Eng.
Glenrose Provincial Hospital
Rehabilitation Engineering Department
EDMONTON, Alberta
T5G 0B7

2.8

DEVELOPMENT OF A MICROPROCESSOR-BASED WHEELCHAIR FEEDBACK CONTROLLER

Robert E. Smith, MSME   William H.T. La, Ph.D.

Palo Alto Veterans Administration Medical Center
Rehabilitation Research and Development Center

ABSTRACT

The Veterans Administration Rehabilitation Research and Development Center in Palo Alto, CA, is undertaking a project to develop microprocessor-based wheelchair motor controllers, with special attention to be paid to the following areas: closed-loop state control; the development of a modular, flexible user interface; and the easy reconfiguration of such a control system under program control.

GOALS

The goals that have been set for this system are straightforward: it is to provide greater maneuverability, and thus greater mobility for the wheelchair user. The technique that first comes to mind is closed-loop control of wheel speed. Since conventional, rear-wheel-drive, castered wheelchairs steer by controlling the relative motion of their drive wheels, accurate control of this motion would appear at this point to promise great advantages; indeed, the one electric wheelchair commercially available at the time of this writing that features an analog feedback controller is indeed somewhat more maneuverable than those without this feature. However, our interest is not limited to speed control: we suspect that the control load placed on the user can be lessened still further by giving the controller some "knowledge" about the machine it is operating, and the user commanding it. For example, a controller should know that it is operating a machine with casters on the front end which may affect the device's "willingness" to move in the direction commanded. Likewise, the controller should know that the user's hand will tend to be pushed back by inertial forces upon acceleration, and should ignore this predictable phenomenon as a spurious command input. Such now-standard features as indoor and outdoor control ranges and response times will also be included.

FEATURES

The resulting controller will have the following features: first, full state feedback using optical incremental shaft encoders. These were chosen because experience shows that they can be made very cheaply in mass production with little or no loss of output quality; this will eliminate the need for expensive high resolution analog tachometers, as well as the intermediate step of analog-to-digital conversion necessary when using tachometers. Second, the controllers will have the equipment required for parameter modification on board in the form of a membrane keyboard and a small LCD alphanumeric display. It is anticipated that work being performed by students at the University of Santa Clara and Stanford University will result in the development of a modular command input format, allowing any of a number of input devices (standard joystick, sip-and-puff, ultrasonic head position, etc.) to be interfaced to the controllers with little or no programming effort on the part of the therapist choosing the input device. We will experiment with having the computer track the condition of the power system using the Miner's Rule method proposed by James A. Kauzlerich of the University of Virginia's Rehabilitation Engineering Center [1], and output its estimate of remaining battery capacity along with standard battery voltage information. A status display will communicate this information, as well as mode, equipment condition, and other useful information on an attractive control panel.

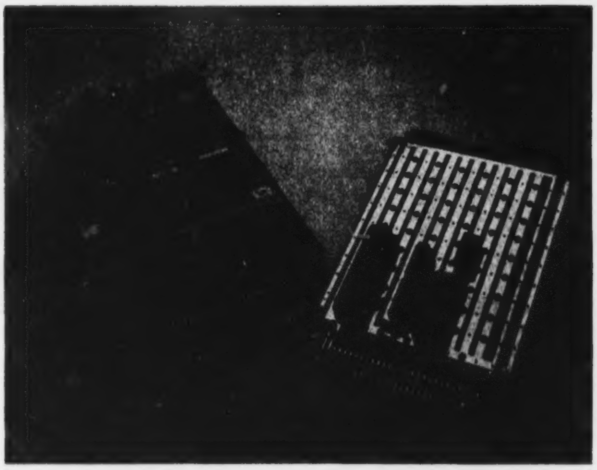
In addition, attention is being paid to the problem of ameliorating controller noise--the penetrating hum emitted by permanent magnet motors when excited by the standard pulse-width modulated power supply.

DEVELOPMENT METHODS

The method used to approach this project differs somewhat from previous work, in that we are undertaking the development of a group of very complete dynamic models of various wheelchairs in cooperation with the Mechanical Engineering Department of the University of California at Berkeley. These models will be used both as input to modern control design procedures, and to provide dynamic parameters for a sophisticated real-time vehicle simulator (a gift from the Singer-Link Corporation) to be installed at the Palo Alto Veterans Administration Medical Center this year. Thus, user preferences can be sampled over a wide variety of possible control configurations before their actual construction, shortening the time between the expression of user preference and the modification of hardware.

A new method of hardware/software/machinery interface development is being undertaken in this project. We will be using a microcomputer built on an industry standard bus (the STD bus) small enough to be easily installed in a relatively small machine such as a wheelchair (see illustration). This microcomputer is equipped with two serial ports, allowing easy communication with a terminal and mass storage. It also plays host to a resident interactive development language, FORTH, stored in an 8K ROM. This language provides unparalleled ease of access to hardware devices in microcomputer systems, making it a powerful tool for the development of these systems, and for the implementation of complex control algorithms. System primitives (code to perform such tasks as the sampling of joystick position and wheel position and speed) can be developed interactively in assembly language by the designers, then used in higher level routines to operate the vehicle. The resulting source code is stored as a file on a disk or other mass storage device allowing easy editing; this source code is then recompiled by the microcomputer each time it is downloaded to that device.

The CPUs chosen are quite powerful, in order to avoid being processor-bound at this early stage of development. We will use the Intel 8088, a 16-bit microprocessor, and its floating-point math co-processor, the 8087 (at the time of this writing, the FORTH package for this pair of processors is still under development; work is proceeding using a 4 MHz Z-80A processor). Our ultimate intent is to produce an inexpensive and manufacturable device using only those features found to be necessary during the evaluation phase with the larger STD computers.



Two STD bus Computer cards that constitute a prototype wheelchair controller.

CONCLUSIONS

The Rehabilitation Research and Development Center is not new to the field of using microprocessors as control elements: the "Smart Wheelchair"[2] uses a microcomputer to interpret the information gathered by its ultrasonic sensors, and the Omnichair's prototype employs a modular, multiprocessing microcomputer for its control[3]. Now, however, we will be using our experience with these experimental systems to develop a more general controller, paying special attention to the various high performance and special capability chairs that are becoming available. It is our hope to generate a configuration that will move the microcomputer-based wheelchair controller from the laboratory to the marketplace, both for conventional wheelchairs and for the more sophisticated machines.

REFERENCES

1. Warren G. Stamp, M.D., and Colin A. McLaurin, Sc.D., *Wheelchair Mobility*, Rehabilitation Engineering Center, University of Virginia, 1982.

2. David L. Jaffe, "Smart Wheelchair," *Proceedings of the Fourth Annual Conference on Rehabilitation Engineering*, September 1981, Washington, D.C.

3. Robert E. Smith and William H.T. La, "User-Computer Interaction in an Omnidirectional Vehicle," *Proceedings of the Sixteenth Annual Hawaii International Conference on System Sciences*, January 1983.

Authors' Address:

Rehabilitation Research and Development Center (153)
Palo Alto Veterans Administration Medical Center
3801 Miranda Avenue
Palo Alto, CA 94304

2.9

COMPUTER ASSISTED EXPERIMENTS WITH THE DISABLED

Namon M. Jackson, Jr., Deborah G. Schmitt, and David R. Weller
Digital Systems Research Department,
Bell Telephone Laboratories
Murray Hill, New Jersey 07974

ABSTRACT

The Computer Assisted Communication System (CACS) is used to explore ways of providing communication assistance to the speech and motor handicapped using a microcomputer and special terminals. The CACS terminal consists of a large typewriter-like keyboard and a cathode ray tube (CRT) display. The terminal is connected to a small self-contained microcomputer. The microcomputer executes programs written to facilitate faster and more versatile communication for a variety of handicapped persons.

INTRODUCTION

The Computer Assisted Communication System (CACS) [1] is currently installed at two centers for developmentally disabled children and young adults. The system is designed primarily for severely motor impaired, nonvocal individuals. Various techniques are being evaluated which include ways of reducing manual dexterity requirements, providing economical text storage and editing, assembling pieces of constructed information into concatenated messages [2], obtaining auditory feedback through a Votrax, and permitting conversation via CRT and the Votrax.

The hardware for the system consists of a DEC LSI 11/23 microprocessor, a 5¼" Micro-Winchester drive which provides over 5 megabytes of storage, and 256 kilobytes of memory. The system has six serial interface ports; one for the system console, another for a printer, and the remainder for CACS terminals. The entire microcomputer is contained in a 19" by 9" by 12" enclosure. A block diagram is included (fig.1).

The CACS communication program allows more efficient construction of stories, letters, etc., and provides storage space for frequently needed phrases [3,4].

The conversation mode is a new concept for CACS users, in which two users have split screens on their displays to send and receive messages. The most recent addition of synthesized speech [5] has enhanced the system even more, and has had very positive effects on the motivation of the users.

Many problems had to be solved before effective use of CACS equipment and programs could benefit the users. A therapist with previous experience with cerebral palsied children was hired to coordinate the research effort with the handicapped users. With active participation of the Cerebral Palsy (CP) Center, The Matheny School, Bell Laboratories CACS Research Group input, and user feedback, new programs were tried and modified on an experimental basis. These were found to give outstanding results for both the handicapped users and the teacher-therapist. The purpose of this document is to give insights into bridging the gap between research and providing useful tools to facilities for the disabled.

BACKGROUND

A CACS terminal consists of a large typewriter like keyboard which lowers the manual dexterity requirements of communication. The keyboard has one inch diameter keys, recessed approximately one-sixteenth of an inch, thereby decreasing the likelyhood of accidentally depressing a key. In addition to the 36 alpha-numeric keys, there are 4 keys for punctuation and 15 which have special functions within the CACS. A key connected to a buzzer within the keyboard is provided for attracting someone else's attention.

The CRT displays 16 lines of 32 characters. The characters displayed are approximately three-eighths of an inch high; this aids any visually impaired user who might have difficulty seeing the 'standard' size terminal characters.

The original CACS consisted solely of the communication program. This aspect of the CACS is used largely for various types of information storage. The availability of this file storage has permitted the children to begin compositions or letters one day and finish them at a later date. This has also facilitated independence where previously a second person was required to be with the child, reading off his language board and writing the information down. The ability to make printed copies supplies the children with a concrete output to show as a result of their work, as well as allowing the children to keep letters more private when this is desired.

The enlarged keyboard (fig.2) that is used with the CACS has allowed severely motor impaired children - who cannot write or use a conventional typewriter - the opportunity to communicate and learn to type within the CACS system. This has given them increased freedom of expression.

COMMUNICATION PROGRAM

A temporary storage area called the scratch pad is provided for constructing phrases or holding arbitrary text. The scratch pad can be displayed on the CRT, stored as a phrase in the phrase book, or appended to a message file. Text is added to the scratch pad by direct keyboard input. To help minimize the number of keystrokes, one and two letter abbreviations for words frequently used are available. Also a word ending capability exists which enables suffixes such as "ing" or "ness" to be added to words by using two keystrokes.

A file called the phrase book is available for storing user constructed phrases. After a phrase is typed into the scratch pad, four keystrokes are required to store it in the phrase book. Stored phrases have a unique two character label assigned to them by the user. By using this label and two additional keystrokes the phrase can be recalled from the phrase book.

There are three message files available to each user for storing text from the scratch pad. These files can be displayed on the CRT or printer. An editor which performs string substitutions is provided for correcting errors within a message file.

CONVERSATION MODE

The conversation program enables two users of the CACS to 'converse' via their terminals. The display on each terminal is divided into two parts, the top half is used to display (echo) the characters typed by the user and the lower half for the messages sent from the conversing user.

After establishing who the two users are the program creates two communication channels (pipes) between the program running on each terminal [6]. These pipes are used to send the message from one user and cursor control information to the other user. The receiving pipe is checked every time the user types a character.

INTERACTIVE FEEDBACK

Due to the vastly different backgrounds of the therapists and Bell Laboratory CACS Research Group members, and the special population of students being served, an interactive program between Middlesex CP Center, The Matheny School, and the CACS Research Group was implemented to improve the system for it's users. To help accomplish this, a therapist with previous experience with the handicapped was hired to learn the CACS and assist with it's further development and use in centers for the handicapped. In this way, feedback was provided through the cooperation of the Centers, the therapist, and the Bell

Laboratories research department.

Another attempt to obtain insight into the users opinion of the system as well as to provide some of the young adults at the Life-Work School at Matheny with a new learning experience led us to ask the students to make a videotape of the CACS. The creativity, humor, and pride in achievement exhibited in the videotape speaks for itself.

CASE STUDIES

Initially the conversation program was used with three young adults who had previous experience with the CACS. As various ways of using the system have developed, we have realized that the possibilities for teaching basic skills such as spelling and math are vast, and we expect that this new option of the CACS will be utilized very much in the future. The following are some specific examples of the various ways the conversation program has been utilized during it's initial six months of use. Benefits to specific users are also documented.

Case 1:

A twenty-one year old male with athetoid cerebral palsy. The most academically advanced of our users, and a creative individual who has used the communication aspect of the CACS to write essays and is currently writing two books about animals. He adjusted to the system quickly, and began asking questions about the availability of the system for his home immediately. When asked if he had any suggestions for changes he would like to see in the development of a new keyboard, he requested that an apostrophe be added. His feeling is that it is important to have when writing letters. He and one other student used the system to drill one another in simple multiplication. He also frequently used the system to ask questions about upcoming demonstrations, and to tell of upcoming events in his life - such as his vacation plans. He has also requested use of the system for conferencing with his work activities program coordinator.

Case 2:

A twenty three year old male with athetoid cerebral palsy. This young man is a social individual, and enjoys making wisecracks. Through the use of the CACS the versatility of his wisecracks has expanded considerably. He is our poorest speller, and has recently received a language board which is arranged phonetically. He uses it nicely, though listeners sometimes have a difficult time interpreting from this phonetic language board. This young man used the CACS to tell his teacher what type of work his sister does - they got stuck on this word because it was not on his language board, and the teacher could not guess the occupation easily.

Case 3:

A twenty six year old female, with very minimal oral speech. She also has athetoid cerebral palsy. This young lady initially sat at the CACS, and did not use it unless someone asked her a specific question. As she became comfortable with conversation, her ability to initiate and her typing speed improved significantly. This case is especially interesting because it brings to focus an issue concerning the socialization process. One can correctly say that this young lady is socially inept. The question becomes: Why? Is there a genuine lack of ability to conceptualize topics for conversation, or has twenty six years of a lack of opportunity to initiate caused this? We may never know, however it is certainly the responsibility of society to minimize this lack of opportunity.

RESULTS OF THE INTERACTIVE PROGRAM

Training with the conversation program proceeded in several steps. After a demonstration of the new program the users spent several weeks casually conversing with the instructor. Next, various teaching drills were devised and tested. Finally, two students were set up at the system together, and encouraged to converse with one another. Several encouraging observations were made during this initial trial period.

During the first two steps, the users expressed pleasure in the amount of freedom the conversation mode provided for them. After becoming acquainted with the conversation program and instructor, the students began relating events of their personal lives (the birth of nieces, changing addresses) to the instructor.

Various uses as a teaching device proved to be quite successful. The uses tested included the following:

1) Drilling of spelling words:

The instructor types three or four variations of a word, and the student types back the correct spelling. For the sake of speed, our student simply typed the number of the correct spelling. If correct, the next word is displayed. If incorrect, the instructor may choose whether to allow the student another guess, or might prefer to give the correct answer and have the student type the correct spelling for reinforcement.

2) Drilling simple math:

The instructor types the problem, and the student replies with the answer. The same format for correct and incorrect answers is used as above.

3) General word usage, grammar, and punctuation:

Throughout general use, the students were corrected when punctuation, spelling, or grammar errors were made.

Early in the training process, the students were set up at the CACS two at a time. Initially, this met with limited success, especially with one particular student who did not seem to be able to initiate a conversation. She would answer specific questions asked of her as if she had her language board in front of her, using yes/no or brief replies. This lack of success is what led us to use of the teaching method previously mentioned between two students. The math drilling was especially successful in this context. The students were told they could not give a problem unless they knew the answer themselves. They enjoyed playing teacher to one another, and this was a way of getting them used to communicating to one another without the intervention of an adult (fig.3).

Finally, as the students became more accustomed to conversing in this manner, they began initiating conversations between one another, forgetting sometimes that the instructor was present. Our student who would never initiate a conversation began asking questions of the other students, and replying in sentences rather than cryptic phrases. She also began expanding the topics of conversation, which were previously limited to concrete happenings, usually specific things she had done recently.

One other use of the system developed spontaneously as a result of the freedom of expression the CACS conversation mode allows. Two of the students requested conferences with their work activities coordinator on the CACS. The coordinator indicated that it actually took longer for these conferences than it would have with their language boards (once a listener becomes accustomed to a specific individual, much of the conversation can be anticipated). She also stated however, that their vocabulary was larger and she did not get delayed for long periods of time trying to guess a word, as she sometimes did if a word was not on the students language board. Certainly the elimination of these frustrations and the increased expressive opportunity for the handicapped individual makes this use of the CACS valuable for both the user and the listener.

The CACS is a unique system, combining teaching and individual use capacities, as well as providing nonvocal individuals with a means of conversing together. While the conversation program is still in the beginning stages, future plans include selective conversation with any one of several users, from one person's home to another, as well as across the room to a classmate, and to remake the keyboard so it could be used as a computer terminal. Other input and output devices being considered for future research with the CACS include systems that could interpret eye movements [7] and a braille keyboard that would be utilized with synthesized speech for the blind.

SUMMARY

By experimenting with new concepts such as these, we are not only opening new avenues of communication to the severely motor impaired nonvocal population, but are also opening new possibilities of self-support and employment for these persons.

In conclusion, through the use of an experienced therapist and the cooperation of the Bell Laboratory Research Group and two Community Centers for evaluation; installation of the CACS at the Middlesex County Cerebral Palsy Center, and The Matheny School have provided direction for future development of new concepts that are more appropriately oriented to the target population. It is recommended that interaction between researchers, teacher-therapists, and the handicapped is necessary to optimize systems for the handicapped population. The more the interaction between these people, the greater the feedback to provide new ideas that benefit the disabled.

ACKNOWLEDGEMENTS

The CACS Research Group is indebted to The Matheny School and the Cerebral Palsy Center at Edison, N.J., and their staff members for much of the one to one work done with the clients. The Bell Laboratories Pioneers, Chapter #54 have provided the much needed monetary support by purchasing the equipment, and have contributed to many projects for both Centers. We are indebted to Dom Giorgi, who has played a major part in overseeing the project from the Poineers viewpoint. We wish to thank our management, A.A. Penzias, R.W. Lucky, H.G. Alles, and G.D. Bergland for their administrative support.

REFERENCES

[1] Tallman, T.M., "Computer Assisted Communication System," presented at the 1976 Conference of Systems and Devices for the Disabled, Tufts University, June 10-12, 1976.

[2] Shannon, M.J. Jr., "A Computer Assisted Communications System," (TM-77-1352-5).

[3] Vanderheiden, G.C. and Grilley, K. (editors), Non-Vocal Communication Techniques and Aids for the Severely Physically Handicapped, University Park Press, Baltimore, 1976.

[4] Dalrymple, G.F., Rowell, D. and Olsen, J., "The Unicom: A Universal Non-Vocal Communicator," Paper prepared for Hawaii International Conference on System Sciences, January 4 & 5, 1979.

[5] Warrick, A., Nelson, P.J., Cossalter, J.G., Cote, C., McGoillis, J., and Charbonneau, J.R., "Synthesized Speech as an Aid to Communication and Learning for the Non-Verbal, Proceedings, Workshop on Communication Aids for the Handicapped, Ottawa, June 8 - 10, 1977. Ottawa: Canadian Medical and Biological Engineering Society, 1978.

[6] Kernighan, B.W. and McIlroy, Unix Programmer's Manual, Seventh Edition, January, 1979.

[7] Rosen, M. and Durfee, W., "Preliminary Report on EYECOM, An Eye Movement and Detection and Decoding System for Non-Vocal Communication," proceedings, Fifth Annual Conference on Systems and Devices for the Disabled, Houston, Texas, 1978.

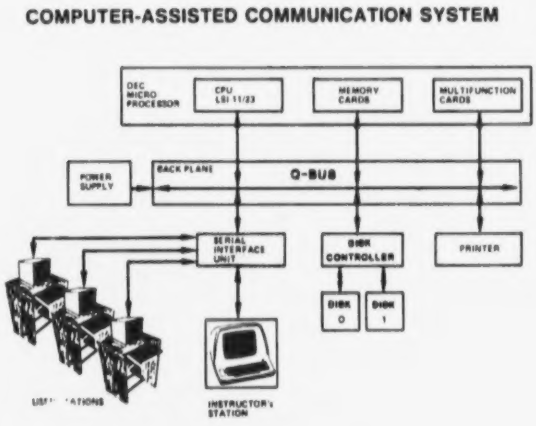


Figure 1
Block diagram of the CACS.

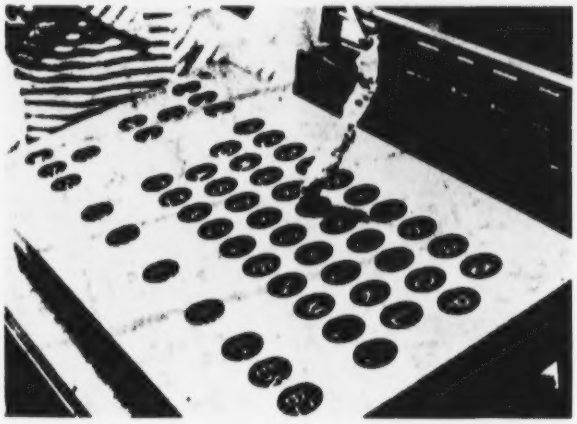


Figure 2
Special keyboard used with the CACS.

Figure 3
Students using the CACS
at the Cerebral Palsy Center.

Contact:
David R. Weller, Bell Telephone Laboratories
600 Mountain Ave., Room 3D450
Murray Hill, N.J. 07974

Microprocessor Instrumentation for Differential Evoked Potential Monitoring

2.10

S.I. Reger, Ph.D, K.C. Chung, M.S., G.J. Wang, MD, and W.G. Stamp,MD.
University of Virginia, Rehabilitation Engineering Center
Charlottesville, Virginia

INTRODUCTION

Quantitative measurements of spinal cord functions and related electrical spinal cord activity are now possible with fast and compact microprocessor techniques. A microcomputer was developed and utilized to sample, store, analyze and display evoked potentials from the central nervous system in the clinic and Operating Room for diagnostic purposes.

A wider availability of microcomputer systems could open new uses of evoked potentials for clinical and experimental purposes (1). We have been studying evoked potentials (2) and their characteristics in experimental spinal cord injury (3) and spinal cord ischemia. An instrument was constructed which used the amplitude and latency of the evoked potentials to follow changes in the neural response during spinal injury.

The purpose of this paper is to describe the characteristics of the dedicated microprocessor based system for signal sampling and analysis from the spinal cord and the cortex.

METHODS

Electrical potentials evoked by peripheral nerve stimulation were recorded from electrodes overlying the spinal cord and cortex from anesthetized cats and human patients. Neural activity from the cord was recorded by pairs of electrodes (K-wires or hypodermic needles) threaded into adjacent spinous processes, while cortical response was recorded subcutaneously from similar 20 ga. needles. An EKG silver-silver chloride electrode was always used for grounding the recording system to the subject paravertebrally or on the abdomen. Recording was simultaneously from two locations of the neuraxis.

A monophasic current pulse or a biphasic voltage pulse (both triggered by the computer) was delivered to a peripheral (typically the tibia) nerve from an optically isolated stimulator. The stimulus frequency was 1, 3 or 10Hz with a duration of 0.1 msec and intensity variable from 1 to 12 times muscle twitch amplitude. Typical stimulus parameters for both spinal and cortical evoked potentials are shown in Table 1.

TABLE I- Stimulus Parameters for Evoked Potentials Recorded From

	SPINE	CORTEX
FREQUENCY	10Hz	3 Hz
AMPLITUDE	4x Twitch	4 or 6x Twitch
DURATION	0.1 msec	0.2 msec
AVERAGED	600 responses	200 responses

The evoked potentials were amplifi differentially by radio frequency isolated preamplifiers, with a total system gain of up to 400,000 and filtered by a bandwidth of 1 to 2200 Hz at the CMRR of 100 dB. Signals from the two channel amplifier could be observed from any two locations of the nervous system, reflecting changes that may occur in between them.

The output of the amplifier is sampled by an LSI-11 digital computer with 32K words of memory, a 12 bit A/D converter, a 0.1MHz real time clock, and a 4 channel serial I/O interface for the graphics terminal and copy unit. Programs and data are stored on floppy disks. With this system, data from two recording sites can be sampled at 10KHz, averaged, displayed and printed in less than two minutes. A block diagram of the system is shown on Figure 1 for spinal and cortical recording.

The averaging strategy used by this system evolved from three previous techniques. First, data was collected by standard ensemble averaging. However, artifacts from heart and muscle activity reduced the quality of the averaged response. Then selective averaging was used, testing each evoked potential for unwanted noise and rejecting the data if noise was present. The stimulus was delivered, even if the data was discarded. In the next procedure, edited averaging, the noise test was done 2 msec before time of stimulation and a stimulus was generated only when cord activity was low. At high background activity, this strategy led to long idling times. Finally, random edited averaging evolved with a continuous noise test until low cord activity was detected, enabling the stimulus pulse. Timing diagram for this stimulus and averaging strategy is shown on Figure 2. The computer controls the stimulus frequency, which fluctuates slightly around the preset 1, 3 or 10Hz depending on the amount of noise detected. This program maximizes the number of stimuli to the subject in the least amount of time with the additional benefit of reduced nerve habituation and fatigue.

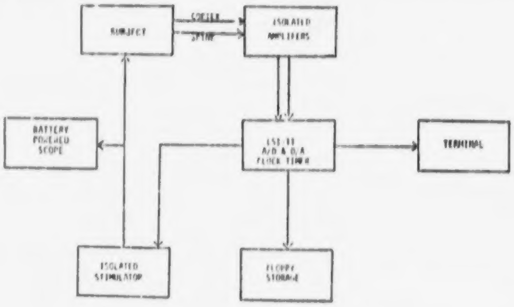


Figure 1 - Block Diagram of Evoked Potential Monitoring System

MICROPROCESSOR INSTRUMENTATION FOR DIFFERENTIAL EVOKED POTENTIAL MONITORING

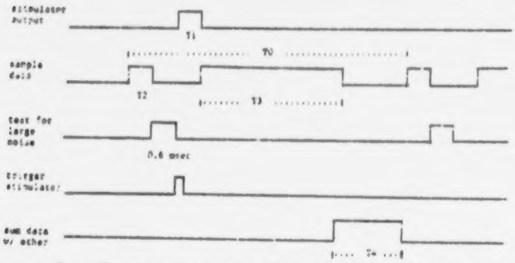


Figure 2 - Timing Diagram for Random Edited Averg.

Timing Analysis for Data Sampling

Stimulus Frequency	3Hz	10Hz
T0 (mesc)	333.3	100.0
T1 (msec)	0.2	0.1
T2 (msec)	4.0	1.2
T3 (msec)	175.0	61.0
T4 (msec)	153.5	37.1

RESULTS

Using this instrumentation for simultaneous recording at cortical and spinal locations, normal multiphasic evoked potentials were obtained. Fig. 3 shows a comparison of these potentials from posterior tibial nerve stimulation. The cortical potentials show larger amplitude with significantly slower components, while signal definition and details of the spinal potentials are more impressive.

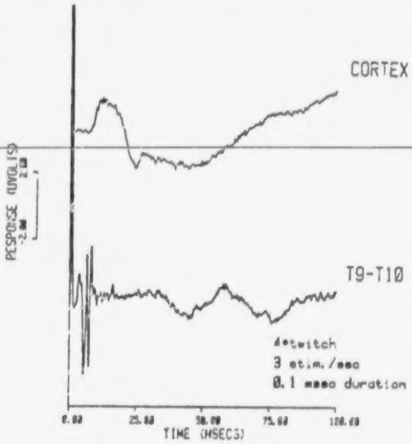


Figure 3 - Comparison of Evoked Potentials. Simultaneous Recording of Spinal and Cortical Evoked Potentials from Tibial Nerve Stimulation of the Cat.

In the absence of stimulus, the output from electrodes and amplifiers could be used to quantitate the inherent background electrical activity in the spinal cord. Figure 4 illustrates the standard deviation of the background or biologic noise activity with increasing Pentobarbital injection. Doses were administered intravenously in 0.2 ml increments over a half hour period. The results, averaged from four cats, show a progressive decrease of electrical activity with increasing depth of anesthesia.

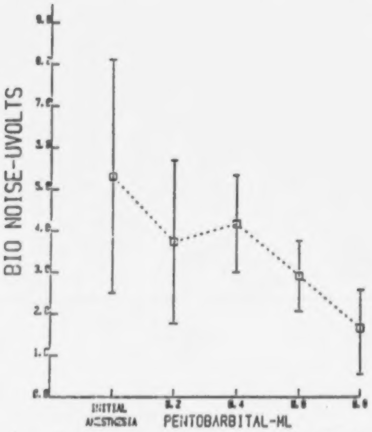


Figure 4 - Reduction of Spinal Electrical Activity with Increasing Depth of Anesthesia

Spinal evoked potentials have been studied from spinous processes to show changes in signal as a result of repeatable standardized mechanical spinal cord trauma porduced in the cat by the drop weight method of Allen (4). Serial recordings of the averaged evoked responses proximal to the injury site at T8-9 are shown on Figure 5 before and after a low level (200g-cm) of cord contusion. The return of evoked potentials preceded neurologic recovery. On Figure 6 no return of evoked potentials are seen after a much higher level of cord contusion. Neurologic function was also not recovered during the four weeks of observation.

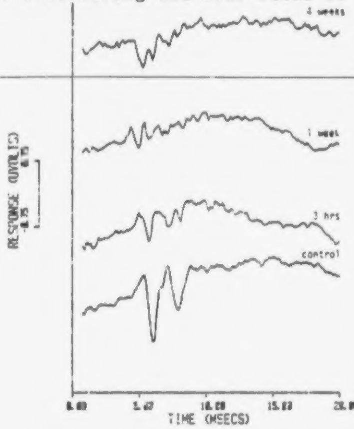


Figure 5 - The Recovery of Evoked Potentials from the Spine at T8-9 Level After 200g-cm Cord Contusion.

The results of acute ischemia studies of the spinal cord is shown on Figure 7 after clamping and release of the aortic arch, proximal to the blood supply to the spinal cord and torso. These recordings show progressive reduction of the negative peak amplitudes with increasing time of occlusion, the release of the aortic clamp was followed by rapid signal return. A near normal recovery in both amplitude and latency was seen within 20 minutes, indicating that temporary obstruction of the blood supply to the cord is not detrimental to the neural conduction in the spinal cord.

Clinical results are shown on Figure 8 from surface recording of spinal evoked potentials. Change in signal confirmed a suspected sensory block at the L3-4 spinal level. Intraoperative recording of cortical potentials are shown on Figure 9. The signals were recorded before and after application of Harrington rod instrumentation for correction of spinal scoliosis. An increase in latency is noticed without change in negative peak amplitudes.

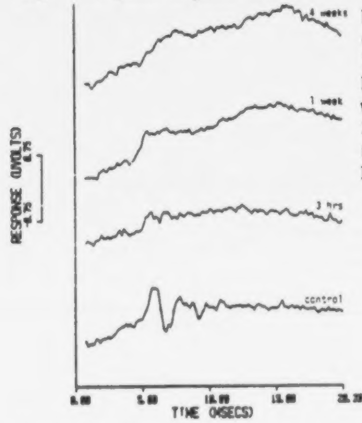


Figure 6 - No recovery of Neurologic Function or Evoked Potentials were seen after 300g-cm Cord Contusion at the T8-9 Level

CONCLUSIONS

The results show that changes in spinal evoked potentials recorded from bone relate well to the extent of cord damage. Using this instrumentation, signal recovery at any degree of injury could be followed for extended lengths of time. An increase in impact energy resulted in rapid and large changes of the observed evoked potentials. Comparative simultaneous recording techniques from two locations offer more reliable interpretation of neural function from spinal and cortical regions.

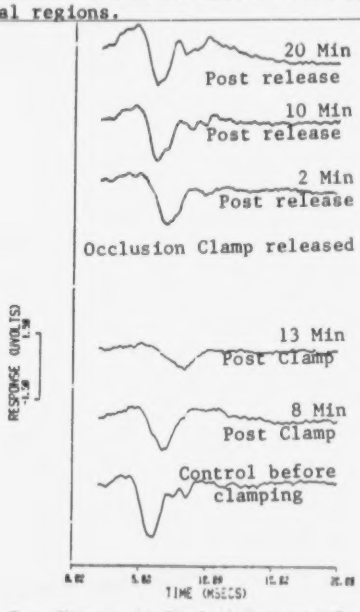


Figure 7 - Change in Evoked Potentials at L1-2 After Occlusion and Return of Spinal Cord Blood Supply

For adequate collection and display of evoked potential data a microprocessor with 8 bit resolution and at least 100K Hz throughput rate is necessary. The CPU must be interfaced with a real time clock with less than 10 usec step interval and 2 A/D converters for input and 2 D/A converters for output and stimulator triggering. Signal reproduction was reasonable with 15 usec skewing time interval between consecutive sample points in two channel sampling. For control and data display, a good quality CRT terminal with graphics capability is also required.

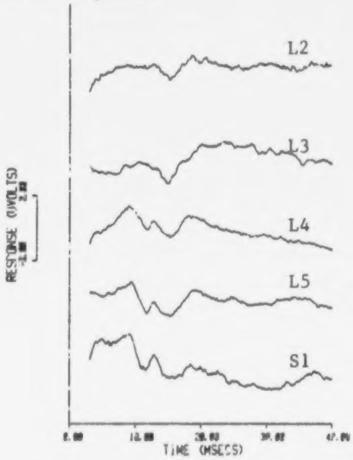


Figure 8 - Clinical Results from Skin Level Recording of Spinal Evoked Potentials.

To complete the system an isolated variable amplitude current or voltage stimulator and two high gain differential amplifiers are also required. Optional peripheral components may include a magnetic data storage device and a plotter. Using existing components an instrument, without permanent data storage, occupying less than one cubic foot of space could be easily constructed.

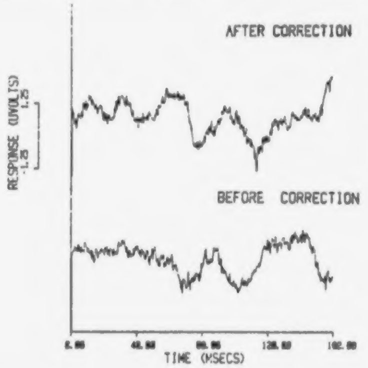


Figure 9 - Cortical Potentials During Surgery. Data was Recorded Before and After Correction of Scoliotic Spinal Deformity

REFERENCES

1.Reger,S.I.,et al,27th Ann. ORS,6:171,1981.
2.Reger,S.I.,et al: Proc. SCMW 2: 95-113,1979.
3.Anderson,C.P., Doctoral Dissertation, UVa,1982.
4.Allen, A.R.: J.A.M.A. 57: 878-880, 1911.

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S.I. Reger, UVa REC, PO Box 3368,
Charlottesville, Virginia 22903

3.1

SPINAL BIOMECHANICS OF TRANSCUTANEOUS ELECTRICAL NEUROMUSCULAR STIMULATION

Jens Axelgaard

Rancho Los Amigos Rehabilitation Engineering Center
Downey, California, USA

ABSTRACT

Electrical muscle stimulation applied through surface electrodes was able to reduce excessive spinal curvatures in both the frontal and sagittal body planes. In scoliosis, the length of the lever arms (ribs) connecting the contracting musculature with the vertebral column determined the amount of curve correction. Thermography was used to detect muscle groups stimulated. A set of guidelines for electrode placement in scoliosis, kyphosis, lordosis, or combinations of these deformities was developed.

INTRODUCTION

Scoliosis curvatures have been induced (1-3) and reduced (4,5) by chronic electrical stimulation of the paravertebral musculature. In our laboratory we found in a biomechanical study, where the distance between stimulation electrodes and straight cat spines was varied, that the average 15° "acute" curvature produced with the electrodes placed on the paraspinals could be improved 3 times if the electrodes were moved to the most lateral trunk muscles (6). The amount of curvature induced did not differ appreciably whether stimulation was subcutaneous or transcutaneous. In spite of the anatomical differences, these results suggest a biomechanical study of the converse effects of stimulating existing spinal curvatures in man.

MATERIALS AND METHODS

Carbon-impregnated silicone-rubber pads with an area of 20 cm^2 were interfaced to the skin via a thin layer of electrolytic gel (Spectra 360). The electrode pads were taped to the skin during roentgenographic documentation of curve change but mounted on cushioned platforms of an adjustable bridge when the distance between the electrodes was optimized through muscle and spine palpations (Figure 1). Neuromuscular stimulation was provided by constant-current square-wave pulses of 200 microseconds duration and at a rate of 30 pulses per second (Figure 2). The variable amplitude was increased from 0 to a fixed level of 70 milliamperes (mA) over a period of 2 seconds every time stimulation was applied. Amplitudes above 70 mA did not improve the already strong muscle contractions significantly and some patients had difficulty tolerating higher levels.

Figure 1. Evaluation stimulator connected to electrodes held in place by bridge

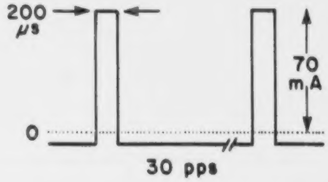

Figure 2. Constant current stimulation pulses

In scoliosis the effect of electrode location was studied in the following manner. The apex of the major curve was determined from a standing anterior-posterior x-ray and marked on the back of the patient. As shown in Figure 3, three electrode locations were established: "Medial", at the center of the bulk of the paravertebral musculature (see Figure 4 also); "Lateral", at the mid-axillary line on the most lateral trunk muscles; "Intermediate", halfway between medial and lateral. In the thoracic region the electrodes were placed symmetrically around the rib joining the apical vertebra and in the lumbar region around an imaginary line perpendicular to the spine through the apex. For all three electrode locations the bridge was used to increment the distance between the electrode centers from 6 cm to 20 cm in 1 cm steps. By palpation of muscle contraction and spinal movement the optimum inter-electrodal distances were found. These measurements and x-ray

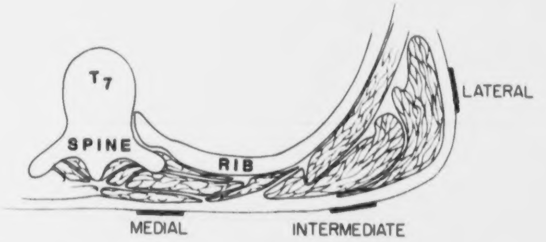

Figure 3. Cross-sectional view of the trunk with the three electrode locations indicated. Measured surface distance from spine to "lateral" is larger than direct distance or lever arm.

documentation of the amount of curve correction were done with the patients in the prone position to eliminate the effect of gravity. Prone x-rays were taken without stimulation and with stimulation of the major curve in a random sequence of medial, intermediate and lateral.

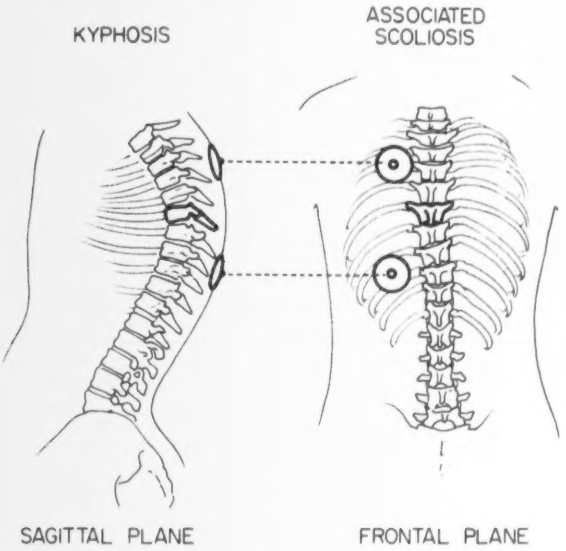

Figure 4. Electrode location for kyphosis with mild associated scoliosis

For kyphosis and lordosis the choice of muscles to be stimulated was limited to those working in the sagittal plane, i.e., the paravertebral musculature for kyphosis and the rectus abdominis for lordosis. The electrodes were placed to the side of the spinal column where the apex of the usual associated scoliosis was located (Figure 4). X-rays without and with stimulation were taken in a sidelying position.

RESULTS

Thirty-two idiopathic scoliosis patients with 35 major curves averaging 25° standing and 50 compensatory curves averaging 18° participated in the electrode placement study. Figure 5 shows a non-stimulated and a stimulated x-ray from a series of four x-rays where the prone major curve measured 13° before stimulation, 8° with medial, 6° with intermediate, and 2° with lateral stimulation. The lumbar non-stimulated curve, which was 16° before stimulation, worsened 3° with medial stimulation but decreased 5° in intermediate and 10° in lateral. For the 35 stimulated curves the average reduction of curvature was 3° in medial, 7° in intermediate and 8° in lateral. An axial de-rotation of 4-6° also occurred with stimulation. These results were all statistically significant ($P<0.05$). From scatter plots of the change of curvature as a function of lever arm for both the stimulated and the non-stimulated curves the regression lines drawn in Figure 6 were calculated. The slopes of the lines were significantly different from 0 ($P<0.05$) and showed better

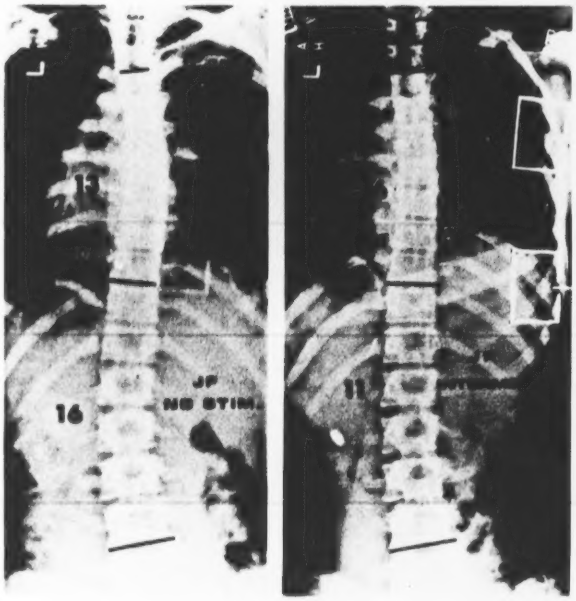

Figure 5. Scoliosis reduction with stimulation

correction the longer the lever arm. If the electrodes were placed on the paraspinal musculature or closer than 7 cm from the spine the non-stimulated curves would worsen.

A thermography study of 5 subjects receiving stimulation showed a heat increase of the working

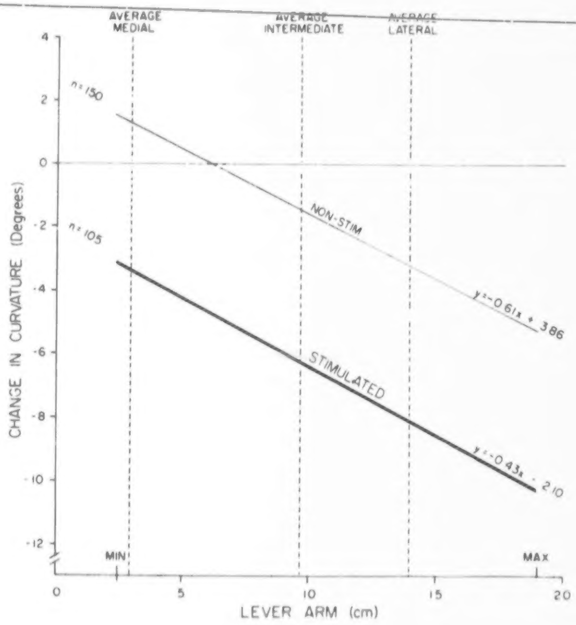

Figure 6. Correction of stimulated and non-stimulated scoliosis curves as a function of muscle lever arm

paraspinous musculature underlying the medially placed electrodes with a spill-over into the lumbar region. With lateral stimulation an increase in heat production was seen from the latissimus dorsi and the lateral abdominals in the thoracic area and the external oblique and the lateral abdominals in the lumbar region.

The kyphosis group consisted of 18 patients with an average standing curvature of 57° which reduced to 47° in the sidelying position. A further correction of 13° (significant at $P<0.05$) was obtained with electrical stimulation (example in Figure 7). On the average, the compensatory non-stimulated lordosis decreased 3°. Lumbar lordosis is rarely treated and only one patient was available for study. The lordosis corrected 17° with stimulation applied.

A regression analysis of the results from stimulating scoliosis and kyphosis concluded that the outcome was neither dependent on curve size or flexibility nor on any other parameter related to spinal curvature.

CONCLUSIONS

From this study a set of guidelines for optimum placement of surface electrodes in the treatment of scoliosis, kyphosis, lordosis or combinations thereof emerged (Figure 8). For scoliosis the average contracted distance between electrode centers was 10 cm and for the sagittal curves it was 12 cm. The lateral placement, 1 or 2 in Figure 8 depending on apex direction, is recommended for scoliosis. The medial placement, 3 or 4 depending on apex direction of associated scoliosis, should only be used for kyphosis. For lordosis the use of rectus abdominis is suggested (5 or 6). Dual channel stimulation may be used for combined deformities in one or two planes.

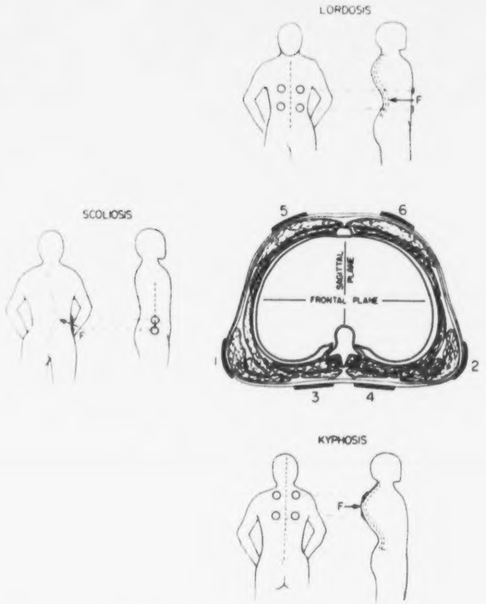

Figure 8. Guidelines for surface electrode placements in the treatment of excessive spinal curvatures

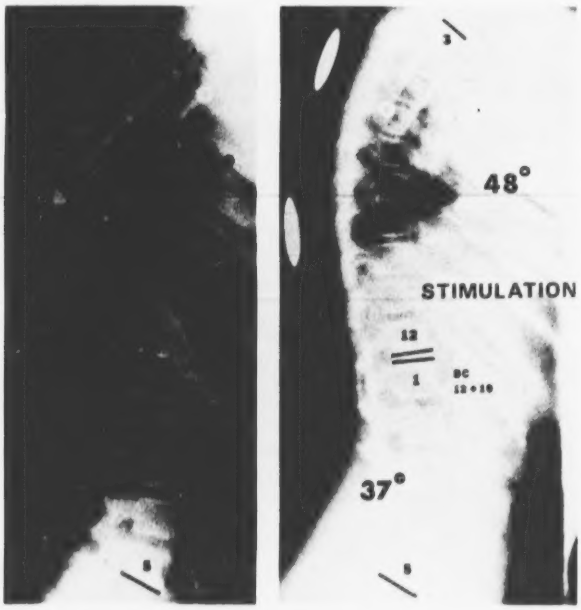

Figure 7. Kyphosis correction by stimulation

REFERENCES

1. Monticelli G, Ascani E, Salsano V, Salsano A: Experimental scoliosis induced by prolonged minimal electrical stimulation of the paravertebral muscles. Ital J Orthop Traumatol, 1:39-54, 1975
2. Olsen GA, Rosen H, Stoll S, Brown G: The use of muscle stimulation for inducing scoliotic curves. Clin Orthop, 113:198-211, 1975
3. Bobechko WP, Herbert MA, Friedman HG: Electrospinal instrumentation for scoliosis - current status. Orthop Clin North Am, 10:927-941, 1979
4. Olsen GA, Rosen H, Hohn RB, Sclocum B: Electrical muscle stimulation as a means of correcting induced canine scoliotic curves. Clin Orthop, 125:227-235, 1977
5. Bobechko WP, Herbert MA, Friedman HG: Electro-spinal instrumentation. J Bone Joint Surg, 58A:156, 1976
6. Axelgaard J: Scoliotic curvature induced by electrical stimulation. Masters Thesis, University of Southern California, 1976, 1-46

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Rancho Los Amigos Rehabilitation Engineering Center, 7601 East Imperial Highway - Bonita Hall, Downey, CA 90242.

ELECTROSTIMULATION AS A MEANS OF DECREASING KNEE FLEXION CONTRACTURES IN CHILDREN WITH SPINA BIFIDA

J. Mazliah,* S. Naumann, C. White, M. Milner,* N.Carroll+
Rehabilitation Engineering Dept, Ontario Crippled Children's Centre
(* and Institute of Biomedical Engineering, University of Toronto and
+ Hospital for Sick Children)

INTRODUCTION

Knee flexion deformity can occur in children with spina bifida who have lesions at the L4-5 neurosegmental level[1]. A common cause of flexion contracture at the knee is a dynamic imbalance between the quadriceps and hamstring muscles.

A pilot study was conducted to measure the efficacy of daily electrostimulation to increase quadriceps muscle strength in such children. This was based upon work by Kralj & Grobelnik (1973)[2] and Mortimer & Peckham (1973)[3] who used electrostimulation to increase both resistance to fatigue and the degree of force generated in patients with paraplegia from traumatic spinal cord injuries. It was anticipated that such stimulation should result in better muscle balance about the knee joint and eliminate or minimize the need for hamstring surgery which tends to weaken hamstring power. There is also the potential to decrease hamstring activity through reciprocal innervation[4].

If bracing is to be employed, this should be facilitated by the resulting increase in quadriceps strength. Thus it was considered that electrostimulation should prevent an increase in flexion contracture at the knee and possibly even decrease it[5].

METHODS

Treatment

Three patients (9-12 years old) with lumbar myelomeningocele and knee flexion contractures above 15° participated in the study. Treatment consisted of one to two hours of daily electrical stimulation of the quadriceps muscles bilaterally over a period of six months. A portable dual-channel neuromuscular electrostimulator (Model 3107 Respond) was used. Stimulation was applied while seated. The knees were set at 30-60° of flexion using elevated leg rests[6]. Both legs were stabilized with ankle weights to prevent movement of the legs during the treatment so that the muscles contracted isometrically. Isometric exercise was prescribed since this was found to be less disturbing to subjects and allowed them to occupy themselves with leisure activities during the periods when electrostimulation was applied.

The active electrode (carbon impregnated rubber) was placed over the lateral muscle bulk of the thigh (vastus lateralis and rectus femoris) with the indifferent electrode positioned just above the patella. The long axis of each electrode was placed perpendicular to the longitudinal direction of the muscle fibres. Stimulus trains of 15 seconds ON and 25 seconds OFF were used with a 4 second rise time at a frequency of 50 hz. Stimulus amplitude was adjusted to tolerable levels. Stimulation was conducted either at home or at school under parent or teacher supervision. The children received a home visit once a month and were assessed at monthly intervals in the Gait Laboratory at the Ontario Crippled Children's Centre.

Assessment

Dynamic gait assessments were performed prior to and following the 6-month treatment period to identify potential changes in gait patterns resulting from the electrostimulation. Clinical girth and strength measurements were performed monthly prior to, during, and after the treatment period. A clinical examination was performed to identify any major changes in the range of motion and muscle power. X-rays of the lower limb were taken before and after the electrostimulation period. The girth of each thigh was measured at 5, 10 and 15 cm from the proximal border of the patella with the knee extended. Strength assessments were performed by measuring isometric torques during maximal voluntary contractions of the knee extensors. The isometric torque tests were performed using a simple mechanical system which took advantage of an existing Kistler force platform in the Gait Laboratory.

The system is depicted in Figure 1. The lever system (a) is pivoted at (b), a Nyliner bearing. Contact with the Kistler #9261A force-platform (g) is by means of wheel (c) thus ensuring the transmission of mainly vertical forces to the plate. An adjustable seat (e) in which the subject is strapped provides comfortable spinal support. Bars (f) prevent lateral thigh movement. A velcro strap between bars (f) ensures no upward movement of the thigh. Lever arm (h) can be adjusted in length and its position on (a) can be

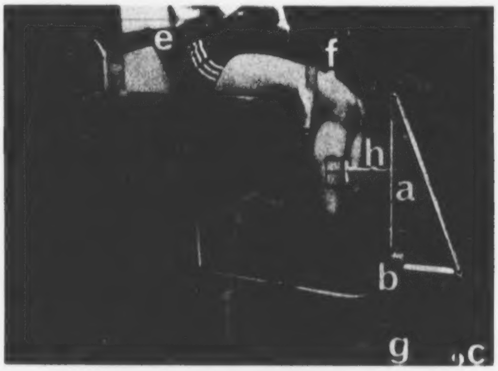

Figure 1: Lever system

varied thereby permitting the accommodation of different leg lengths and thicknesses.

The relationship between the force measured and that exerted by the leg for different positions of arm (h) along lever (a) was measured using a calibration jig. The jig consists of a frame bolted into the floor, a platform on which weights can be supported, and a pulley on a post whose height can be varied. A nylon rope transmits the force of the weight to arm (a) of the level system. Force- plate data were sampled at a frequency of 100 Hz for 10 seconds. Four repeated runs for each weight and lever-arm length were averaged and calibration curves were calculated as depicted in Figure 2. These curves permit the force exerted to be calculated from forces measured at the force plate.

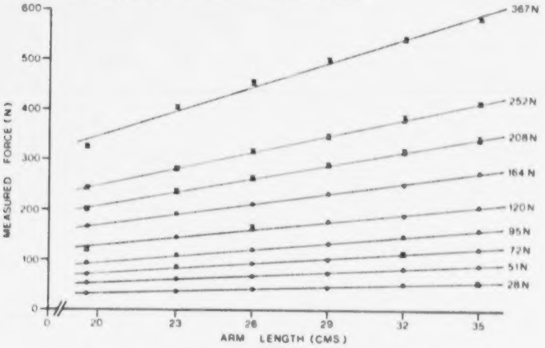

Figure 2: Calibration curves of force measured versus arm length for different known applied forces.

The patients were seated as shown in Figure 1. Verbal instructions were given during the tests to encourage the subjects to exert maximum effort. The isometric test consisted of eight trials, 3-6 seconds in duration with at least two minute rest periods between trials to minimize the effects of fatigue. For every trial, the forces measured during a 500 mS period about the maximum were averaged. The total force was calculated by averaging these values for the eight runs.

RESULTS

Of the three subjects, one demonstrated no significant changes in thigh girth, the degree of fixed contractures at the knee (18° and 22° for left and right knees respectively), or maximum volitional isometric moment (16 Nm and 30 Nm on the left and right sides respectively). The second subject had an 8 degree fixed flexion contracture bilaterally, and dynamic contractures which varied between 10 and 30 degrees from occasion to occasion). No changes were noted on the left side. Thigh girth on the right increased by 3 cm and the moment about the knee increased by 44% over the stimulation period (from 9.3 to 15.3 Nm). A benefit of stimulation was a decrease in hamstring spasticity. This was noted clinically and by the subject's mother but did not manifest itself in increased moment measurements on the left side.

The third subject had undergone surgery on the right hip because of subluxation. Transfer of iliopsoas did not correct the problem and a subsequent pelvic osteotomy was required. A fixed knee flexion contracture of 17 degrees was measured radiologically on the left side prior to stimulation. At the end of the 6 month stimulation period, this contracture had decreased to 10 degrees. Figure 3 depicts the measured isometric knee moments (mean and standard deviation) for both sides during the experimental period. Second order regression curves have been fitted to the data recorded during the stimulation period. No change in thigh girth was noted over the entire 46 weeks. The drop in the moments at the 28th week on the right side and on the left side at the end of the stimulation period corresponds to a period of urinary tract infection. No electrostimulation was applied during the last 3 weeks of this period. As a result of increased quadriceps strength, ankle-foot-orthoses were prescribed instead of knee-ankle-foot-orthoses which had been used previously.

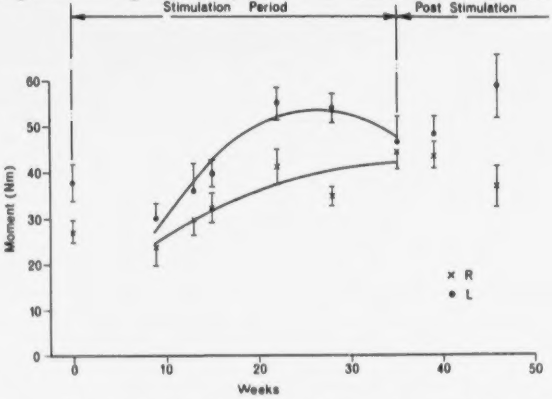

Figure 3: Moments developed about the knee joint during maximum isometric quadriceps contractions versus time.

DISCUSSION

A confounding factor in the type of study described here is the reliance of the experimentor on the subjects and their families to implement a home-based electrostimulation program. Although home visits were made regularly, and subjects and their families were repeatedly instructed on the placement of electrodes, appropriate stimulus intensity and duration, these instructions were not always followed. It is therefore not possible to fully explain the changes or lack thereof that occurred during the study.

In two of the subjects, greater isometric knee moments were consistently measured on the side with a greater knee flexion contracture. A possible explanation for this in the third subject discussed is the unstable hip on the side with no contractures. Although efforts were made to stabilize the thigh during the measurement procedure, the possibility of the femur moving in its surrounding soft tissue cannot be discounted. Of interest in these two subjects is the drop in isometric knee moment after one month of stimulation that may indicate an initial period of rapid fatiguing of the muscle. There is no ready explanation for the observed increase in post-stimulation isometric moment for the left side as reflected in Figure 3. All subjects will be followed in the laboratory for a further 2 months so that the carry-over effects of electrostimulation can be further clarified. The lack of correlation between changes in muscle moments and thigh girth has been previously reported on in the literature[7]. Analysis of data from the gait studies are presently being analyzed and will be presented.

CONCLUSIONS

This study demonstrates that electrostimulation may be useful in increasing quadriceps muscle strength and maintaining or decreasing knee flexion contractures in spina bifida children with low level lesions. In the three subjects studied, no increase in the degree of the contractures was noted. In one subject, the contracture was reduced from 17 to 10 degrees. The practicalities of implementing a home-based electrostimulation program in order to conclusively document its effects need further consideration. Motivation on the part of subjects and their families is often lacking since immediate benefits are not apparent. Lack of supervision in applying electrostimulation may also result in a less than optimum implementation of the stimulus regime. The use of percutaneous or implanted electrodes will have to await evidence that the benefits of this form of electrostimulation warrant using an invasive technique.

ACKNOWLEDGEMENT

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REFERENCES

1. Stark, G.D. (1977): "Spina Bifida: problems and management", Blackwell Scientific Publications, London, England.

2. Kralj, A., Grobelnik, S. (1973): "FES - a new hope for paraplegic patients?", Bull. Pros. Res., (Fall), pp. 75-102.

3. Mortimer, J.T., Peckham, P.H. (1973): "Intramuscular electrical stimulation", in (Eds: W.S. Fields, & L.A. Leavitt) Neural Organization: Relevance to prosthetics, Intercont. Med. Book Corp., New York, pp. 131-145.

4. Levine, M.G., Knott, M., Kabat, H. (1952): "Relaxation of spasticity by electrical stimulation of antagonist muscles", Arch. Phys. Med., 33, pp. 668-673.

5. Munsat, T.L., McNeal, D., Waters, R. (1974): "Preliminary observations on prolonged stimulation of peripheral nerve in man". Proceedings of the Third International Congress on Muscle Diseases, pp. 42-50.

6. Benton, L.A., Baker, L.L., Bowman, B.R., Waters, R.L. (1981): "Functional electrical stimulation - A practical clinical guide", Rancho Los Amigos Rehabilitation Engineering Centre, Downey, California.

7. Romero, J.A., Sanford, T.L., Schroeder, R.V., Fahey, T.D. (1982): "The effects of electrical stimulation of normal quadriceps on strength and girth", Med. Sci. in Sports and Med., 14:3, pp. 194-197.

Ontario Crippled Children's Centre
350 Rumsey Road,
Toronto, Ontario
M4G 1R8

3.3

LINEARIZATION OF AN OPEN LOOP FUNCTIONAL NEUROMUSCULAR STIMULATION SYSTEM THROUGH A PIECEWISE LINEAR APPROXIMATION

G.B. Thrope, P.H. Peckham, P.E. Crago, S.D. Braswell, J.R. Buckett
Case Western Reserve University/Rehabilitation Engineering Center

ABSTRACT

Functional neuromuscular stimulation (FNS) systems which require precise control of muscle force must have the capability to compensate for the nonlinear input/output relationship of stimulus to response (1). A technique has been developed which utilizes a piece wise linear approximation to control the muscle°s recruitment properties during electrical stimulation to linearize the muscle°s output response. This technique has been incorporated into the software of our laboratory's computer controlled multichannel stimulation system (2) and our present version of a patient based microprocessor controlled system. The optimization of our open loop system has proven to be of great value in enhancing the performance of the FNS system.

INTRODUCTION

The use of FNS in controlling the hand of a quadriplegic has been presented(3,4). A hand system must operate in a repeatable and predictable manner in order to satisfy the performance criteria that is needed to enable a patient to effectively use his hand. Previously, laboratory and functional systems that had been developed to control the hand had a fixed minimum and maximum parameter limit and a linear modulation of stimulus pulse width and/or frequency for each channel of stimulation. This was due primarily to hardwired circuitry constraints (5). These systems were unable to compensate for nonlinear recruitment characteristics of the stimulated muscles . The optimization of the open loop input/output relationship of control to muscular response can be compensated for by utilizing a piecewise linear technique to insure a smoother overall muscular movement.

MOVEMENT PLANNING AND COORDINATION

A real time process translates the control parameter (that is produced by the subject or the investigator) into the set of stimulus parameters that corresponds to each control parameter level. No constraints are placed on the relationship between input command and output pulse width. We have chosen to use lookup tables to simplify this process, which allow for straightforward implementation of piece wise linear modulation of stimulus parameters. The input control parameter is treated as having 8 bit resolution, and one 256 element integer array is allocated for pulse width modulation for each channel and IPI modulation of each group. Channels within a group are activated in a fixed sequence (for a constant IPI, the phasing of one channel with respect to the next is 360 degrees divided by the number of channels in a group). The contents of each PW array (filled during the parameter set up procedure) are the values to be loaded into the D/A registers to produce the desired pulse width corresponding to each possible value of the command. The contents of each IPI array are the actual IPI's to be sent to the stimulus timing process.

The process operates in a continuous loop, ie., it is not synchronized to a clock. Each time through the loop, the input control signal level (in the range from 1 to 256) is used as an index to the lookup tables for each of the channels and groups in use. The contents of the PW lookup tables at that entry are then loaded into the D/A's. This does not in itself elicit stimulus pulses; triggering is accomplished by a separate real-time process.

LABORATORY SET-UP

The operator of the laboratory system has as his initial objective to choose the appropriate stimulated muscles that will provide the type of functional movement he desires. Each of the muscles are characterized by their recruitment pattern and their temporal summation pattern. Once the individual electrodes are characterized, they are typically assigned one common control signal that will coordinate the stimuli to all muscles. An example of the relationship between input control and output stimulus to achieve a lateral prehension grasp is seen in Figure 1.

LINEARIZATION OF THE OPEN LOOP SYSTEM

The relationship between the control signals (derived from the command signals) and the stimulus parameters may be specified for each channel. The system utilizes a piece wise linear approximation of PW and IPI modulation to correct for the nonlinear modulation of muscle force by recruitment (1) and the nonlinearities of muscle loads (Fig. 2). Piecewise linear relationships can be specified between a single continuous control signal and the IPI and PW of each channel. No restrictions exist on the order, slope, or degree of simultaneous modulation of IPI and PW on a single channel. The coordination of different muscles is achieved by specifying simultaneous modulation of stimulus parameters in different channels by the same control signal. No restrictions are placed on coactivation of antagonistic or synergistic muscles. The piecewise linear relationships are specified by the end points of individual linear segments. These end points can also be specified or altered while stimulation is taking place by assigning the control of individual channels to specific potentiometers on the A/D interface. Thus one (or more) channel(s) can be controlled independently of the others so that its contribution to the coordinated movement can be assessed or altered. When the stimulus parameters for that channel are appropriate (as assessed by visualization or measurement of the movement), that combination of stimulus parameters can be entered automatically as one of the end points of a linear segment. Up to 20 straight line segments can be specified for each channel.

CONCLUSION

The application of FNS to aid in the restoration of upper or lower extremety function needs a sophisticated level of input signal processing to enable the patient to operate the system in a simple and straightforward manner. A repeatable and predictable pattern of muscular response is a highly sought after criterion to insure the patient of the effectiveness of his neuroprosthetic device. In our systems we have been using a piece wise linear approximation to linearize the command input to stimulus output response. This process has enabled our open loop FNS systems to perform in a smoother pattern. Yet we view the technique of piece wise linear approximation as just one additional process to better control our FNS systems.

Open loop controlled FNS systems are desirable at this time because of their ease in application. Although we have increased the performance of these systems by a piece wise linear approximation, we believe that areas of research including closed loop control, better patient/controller interface techniques, and the processing of controller signals, to mention just a few, can better enhance the overall system.

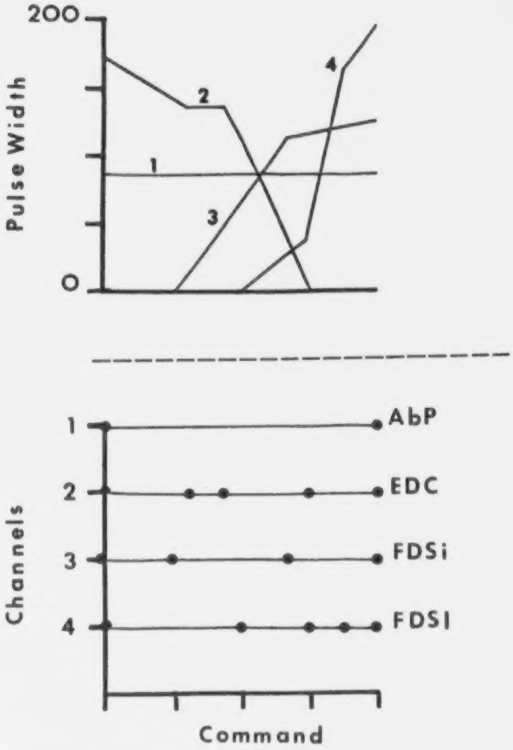

Figure 1. The relationship of a piece wise linear approximation of four channels of stimulation with the input commands to achieve a palmar prehension grasp. The upper figure demonstrates the relationship of the break point regions for each channel with respect to one another.

In this example, the thumb is maintained in a relatively fixed position by the Abductor pollicus(AbP). At 0 % of command the fingers are fully extended by the Extensor digitorum communis (EDC). As command increases the pulse width for the EDC starts to decrease while the stimulation to the Flexor digitorum superficialis of the index and long fingers (FDSi, FDSl) increase at varying degrees. The effect of utilizing this technique is to achieve a more linear finger response for the palmar prehension grasp.

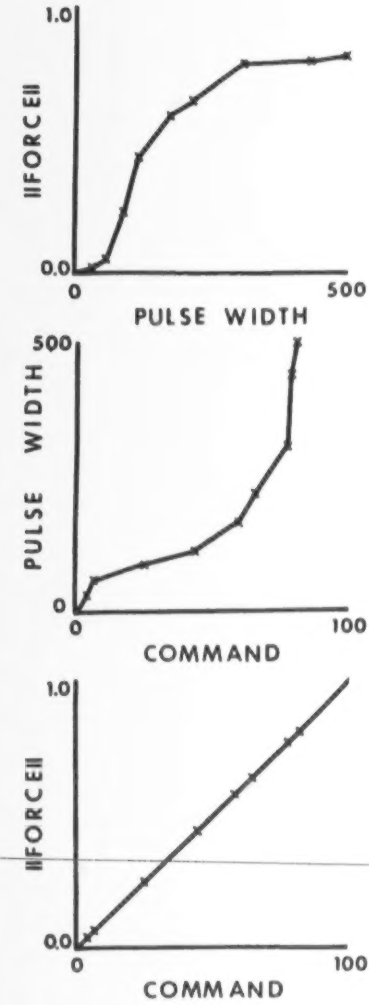

Figure 2. The upper figure represents the recruitment characteristics of a cat soleus muscle with the force normalized to the maximum physiological force (1).

The middle figure demonstrates an inverse relationship of pulse width to command. By using the piece wise linear technique of pulse width and command, a completely linear relationship of output response (force) to input command may be generated, as shown in the lower figure.

REFERENCES

1. Crago, P.E., Peckham, P.H., and Thrope, G.B. "Modulation of muscle Force by Recruitment During Intramuscular Stimulation". IEEE Trans. Bio. Eng. BME-27, No. 12, 679-684, 1980.

2. Thrope, G.B., Peckham, P.H., and Crago, P.E. "A Computer Controlled Multichannel Stimulator for Laboratory Use in Functional Neuromuscular Stimulation". Proceedings of the 4th Annual Conference on Rehabilitation Engineering, Wash., D.C., 1981.

3. Peckham, P.H., Marsolais, E.B., and Mortimer, J.T. "Restoration of Key Grip and Release in the C6 Quadriplegic Through Functional Electrical Stimulation". J. Hand Surg., Vol. 5, No. 5, 462-469.

4. Peckham, P.H., Mortimer, J.T., and Marsolais, E.B. "Controlled Prehension and Release in the C5 Quadriplegic Elicited by Functional Electrical Stimulation of the Paralyzed Forearm Musculature". Annals of BME, Vol. 8, No. 4, 1981.

5. Strother, R.B., Buckett, J.B., and Peckham, P.H. "A Functional Neuromuscular Stimulation System for Control of Grasp and Release". Proceedings of the 4th Annual Conference on Rehabilitation Engineering, Wash., D.C., 1981.

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Correspondence should be sent to G.B. Thrope, Case Western Reserve University Rehabilitation Program,Clevelan Metropolitan General Hospital, 3395 Scranton Road, Cleveland, Ohio 44109

ACUTE AND CHRONIC IMPLANTATION OF COILED WIRE INTRANEURAL ELECTRODES

Bruce R. Bowman, Sc.D.
Rancho Los Amigos Rehabilitation Engineering Center
Downey, CA 90242

ABSTRACT

The posterior tibial nerves of 16 rabbits were intraneurally implanted with 0.25 mm diameter coiled wire electrodes for up to nine weeks. One group was acutely implanted in one leg while the other leg was chronically implanted. A second group was chronically implanted and stimulated in one leg and chronically implanted without stimulation in the other leg. Nerve histology showed little or no demyelination or denervation in most specimens. Little change in motor current threshold was observed beyond ten days post implantation. No significant changes in nerve conduction velocities between the time of implantation and eight weeks post implantation were observed.

One cat was implanted with four intraneural electrodes for a four year period. Threshold current showed very little change during the implantation period.

INTRODUCTION

The future of electrical stimulation using implantable devices is dependent upon achieving safe non-reactive delivery of electrical currents to the nerve or muscle. One means of successfully achieving this is through use of an electrode which is loosely wrapped around the nerve to be stimulated.[1,2] One disadvantage, however, of such an electrode is a large amount of scarring produced about the electrode making revision or removal difficult. Another disadvantage is the lack of selectivity of the fibers being stimulated within a large nerve bundle.

The use of a different type electrode implanted intraneurally was reported in 1967 by Sheldon, Pudenz, and Doyle[3] for electrical control of facial muscle spasms and trigeminal pain. Solid wire electrodes were successfully inserted in the facial nerve and mandibular branch of the trigeminal nerve. No follow-up study or pathological evaluation of nerve sections were reported.

A coiled wire electrode similar to that developed and clinically applied at Case Western Reserve University utilized for intramuscular stimulation[4,5] was evaluated in the current study for intraneural stimulation. The electrode, unlike the solid wire used by Sheldon, is formed into a flexible coil allowing expansion and contraction within the surrounding tissues, and adding additional resistance to breakage. The purpose of this study was to determine the feasibility of utilizing intraneural coiled wire electrodes for chronic stimulation of peripheral nerves.

MATERIALS AND METHODS

The intraneural electrodes were made from nylon-coated number 304 stainless steel wire .05 millimeters in diameter wound into a 0.25 mm diameter helical configuration 20 cm long, similar to the type described by Caldwell and Reswick[5] but without a silastic core. The final one centimeter of each section of coiled wire was deinsulated and crimped to a 1.7 cm long 30 gauge injectable needle used for insertion into the nerve.

The indifferent electrode consisted of four 7 cm long sections of multistrand platinum braided wire .5 mm in diameter attached to the end of the stimulation unit.

The implantable stimulators developed for this study delivered constant current capacitively coupled square wave pulses 220 microseconds in duration. A transmitting antenna was placed around the inside wall of each animal cage and used to control ON and OFF times as well as allowing for adjustments of stimulus amplitude regardless of the animal's position in the cage.[6]

Implantation of the intraneural electrode was performed by inserting the needle through the tibial epineurium at a small angle with respect to the nerve and passing it longitudinally just within the perineurium for one centimeter and brought out again through the epineurium (Figure 1). The wire was pulled through the nerve until the entire 1 cm long section of deinsulated coil was within the nerve. The needle and excess wire was cut off flush with the nerve sheath.

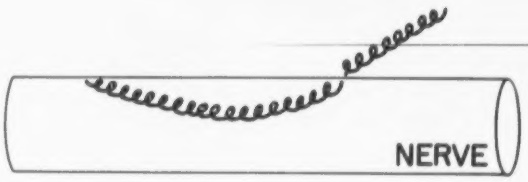

Figure 1
Placement of Coiled Wire Electrode

Eight animals were included in Group A to study the effects of acute and chronic implantation on nerve integrity. After electrode insertion in the right nerve of each animal, the electrode was removed prior to closure. On the left nerve the electrode was left in place and the coiled wire was passed subcutaneously to the lower back where a nonfunctioning stimulation device was attached and sutured to lumbosacral fascia. The animals were studied for an eight week period.

Eight animals were included in Group B to study the effects of chronic implantation with and without electrical stimulation on nerve integrity. The left tibial nerve of each animal was implanted and the wire passed subcutaneously to the lower back and attached to an active stimulation device (Figure 2). The right tibial nerves were

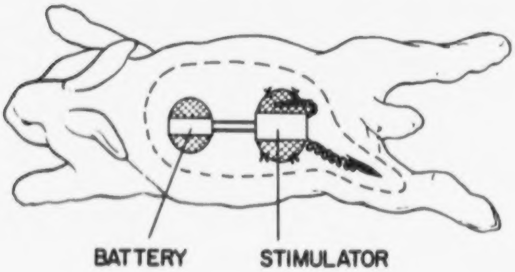

Figure 2
Implantation Site of Stimulators

chronically implanted, however no electrical stimulation was applied through the electrodes.

Electrical stimulation was applied cyclically to the intraneural electrodes of the animals in Group B for seven seconds, followed by relaxation for 23 seconds, for a one hour period every four hours. Stimulation continued for 3-8 weeks. The pulse repetition rate was set at 50 pulses per second with a pulse duration of 220 microseconds at an amplitude twice threshold which resulted in a strong contraction.

Nerve conduction velocity was measured bilaterally on the animals in Group A prior to implantation with the tibial nerve exposed. Eight weeks following intraneural electrode implantation of Group A and 3-8 weeks following implantation of Group B, conduction velocities of the tibial nerves were remeasured bilaterally.

At the time of sacrifice of both Group A and Group B animals, the tibial nerves were excised bilaterally and electrodes removed. Nerve sections were obtained at levels proximal, distal, and through the electrode site and stained using H & E and luxol fast blue.

RESULTS

Periodic observation of the animals, both in their cage and out, demonstrated no observable favoring or loss of plantar flexion function in any of the rabbits implanted.

Gross examination of implants at sacrifice showed that none of the electrodes had pulled out of the nerve. The wire showed no connective tissue formation along its course to the nerve. Examination of the wire in the nerve under a dissection microscope showed little or no reaction in most nerves although in about 40% of the nerves a bulbous enlargement was seen at the points of electrode entry and/or exit from the nerve. These findings were not consistent and could not be correlated with animal Group or side of implantation.

Statistical analysis of conduction velocities recorded on the six Group A animals completing an 8 week implantation period showed no significant differences between conduction velocities pre implantation versus eight weeks post implantation in either the acutely implanted or chronically implanted nerves. Statistical analysis of conduction velocities recorded on the seven Group B animals completing a 3-8 week implantation/stimulation period showed no significant difference between conduction velocities of the chronically stimulated nerves and those not receiving stimulation.

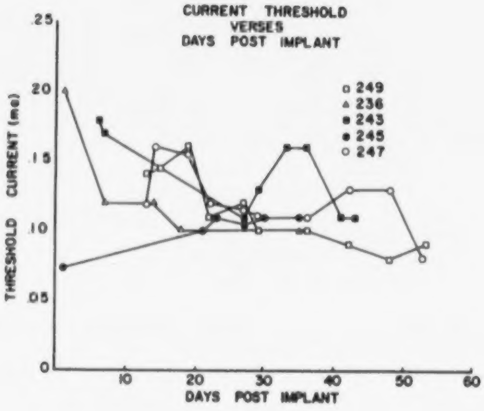

Figure 3
Current Threshold During Implantation Period of Rabbits Receiving Chronic Electrical Stimulation

Threshold data was measured biweekly on the stimulated Group B rabbits. A graph of threshold for the five animals receiving at least 5 weeks of cyclical electrical stimulation is shown in Figure 3. Thresholds ranged from .07-.20 ma at the time of implantation. By 14 days post implantation, thresholds stayed relatively constant between .08 and .16 ma throughout the implantation period of up to 54 days.

One cat was implanted with four intraneural electrodes (peroneal and tibial nerves of each leg) terminating in transcutaneous carbon buttons with magnetic connectors[7] which allowed direct current measurements to be taken over extended periods. Figure 4 shows current threshold during the 48-month implantation period. After 5 months one electrode became intermittent (Rt.T) as a result of wire breakage. Two other electrodes were operating satisfactorily when the transcutaneous buttons were pulled out by the animal - one at 5 months (Lt.P) and the second at 18 months (Rt.P). The fourth electrode (Lt.T) continued to function until time of sacrifice at 48 months but showed a sudden rise in threshold sometime during the fourth year.

Histological sections of nerves proximal and distal to electrode implantation sites showed consistent lack of reactions with only occasional and minimal fiber denervation. Sections taken through the electrode site however showed inconsistent reactions which were not correlated to length of implantation or whether or not stimulation was applied. A section taken through the electrode site, of a nerve implanted for nine

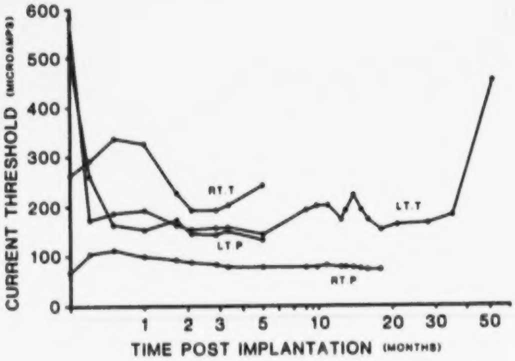

Figure 4
Current Threshold of Four Nerves During Four Year Implantation Period in a Cat

weeks and stimulated for eight weeks shown in Figure 5 taken through the electrode site, (luxol fast blue), shows the location of the electrode as a circular hole. This hole is exaggerated in size due to the removal process. This section appears as normal tibial nerve with a possible small connective tissue reaction at the lower right.

In another animal stimulated for eight weeks a great deal of reaction was observed. A cross section passing through an area just distal to the exit site showed a large amount of connective tissue proliferation on the side of the nerve that the electrode was placed but completely normal nerve on the opposite side of this section.

The real significance of the occasional reactions at electrode entrance and exit sites is not understood. Because distal sections showed normal nerve fibers these reactions may not be alarming.

CONCLUSIONS

The intraneural electrode appears to have potential as being an alternative means of applying chronic electrical stimulation. The current required to stimulate the nerve using the coiled wire was 5 to 12% of that required of conventional wrap-around electrodes[2] and approximately 0.5-1% that required for intramuscular electrodes.[4] Threshold remained relatively constant even over extended implantation periods. Conduction velocity studies as well as pathology suggest that no serious nerve damage occurred however further studies are needed to better define long-term effects of implantation and stimulation.

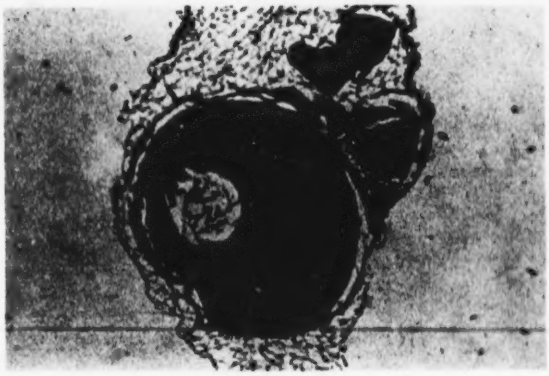

Figure 5
Nerve Section Through Electrode Implantation Site

REFERENCES

1. Glenn WWL, Holcomb WG, and McLaughlin AJ: Total Ventilatory Support in a Quadriplegic Patient with Radio Frequency Electrophrenic Respiration. New Eng J Med, Vol. 286, 10:513-516, March 1972.
2. Waters R, McNeal D, and Perry J: Experimental Correction of Footdrop by Electrical Stimulation of the Peroneal Nerve. J Bone Joint Surg, 57A:1047-1054, 1975a.
3. Sheldon H, Pudenz R, and Doyle J: Electrical Control of Facial Pain. Am J Surg, 114:208-212, 1967.
4. Mortimer JT and Peckham PH: Intramuscular Electrical Stimulation, in: Neural Organization and its Relevance to Prosthetics, Fields, WS and Leavitt, LA, eds., Intercontinental Medical Book Corp., New York, pp 131-146, 1973.
5. Caldwell CW and Reswick JB: A Percutaneous Wire Electrode for Chronic Research Use. IEEE Trans, 5:429, 1975.
6. Su N, McNeal D, and Bowman B: An Externally Powered Implantable Neurostimulator for Caged Animal - A Powering Scheme for Implantable Stimulators. Presented at the Association for the Advancement of Medical Instrumentation, Boston, Mass., March 1975.
7. Mooney V and Roth AM: Advance in Percutaneous Electrode Systems. Biomaterials, Medical Devices and Artificial Organs, Vol. 4, No. 2, 1976.

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Rancho Los Amigos Rehabilitation Engineering Center, 7601 East Imperial Highway - Bonita Hall, Downey, CA 90242.

A MICROPROCESSOR BASED PORTABLE FUNCTIONAL ELECTRICAL STIMULATION SYSTEM

J.R. Buckett, S.D. Braswell, G.B. Thrope, P.H. Peckham

Case Western Reserve University/Rehabilitation Engineering Center

ABSTRACT

A small portable functional electrical stimulation system utilizing a microprocessor has been developed. Incorporation of the microprocessor has resulted in a user device which can be programmed to accept and process a variety of user generated commands and output complicated stimulus patterns. The availability of these enhanced stimulus regimes and more complex user control algorithms enable us to tailor the device to a large population of potential users.

BACKGROUND

For ongoing evaluation of FES hand grasp systems (1,2) outside of a laboratory environment our center developed two small portable functional electrical stimulation systems (3,4). Individuals participating in our FES studies are provided with a system for daily outpatient use. The systems which have been developed provide both stimulation and control functions which duplicate those generated by the laboratory system. There were two versions of stimulators being used in our studies. The major difference is the technique by which the user controls the stimulation regime. One system utilizes a proportional input, whereas the second system uses a gated ramp to grade stimulus output.

Due primarily to power consumption constraints, both control algorithms were implemented in discrete hardware state machines. Flexibility of this design is limited since major control algorithm changes require hardware redesign.

With the advent of the CMOS microprocessor, a programmable FES system has been developed to overcome the limitations of the earlier two systems. The primary design objectives were to:

1) Maintain a small sized package
2) Use a slightly modified version of the existing stimulator circuit board
3) Increase the number of inputs
4) Increase the number of outputs
5) Use a single +5 volt power source
6) Keep current consumption low

MATERIALS AND METHODS

Hardware

A functional block diagram of the microprocessor based portable functional electrical stimulation system is given in Figure 1. There are five basic sections. The input/output processing section is responsible for signal conditioning (ie., gain and simple filtering, if necessary) of up to eight analog input signals. It also generates the oscillator drive signal used with our shoulder position transducer (5). Five of the eight analog output channels are used to control the stimulus parameters as described later. Two of the channels are used to implement the auto set point of the shoulder transducer. The last analog output channel controls an audio tone generator.

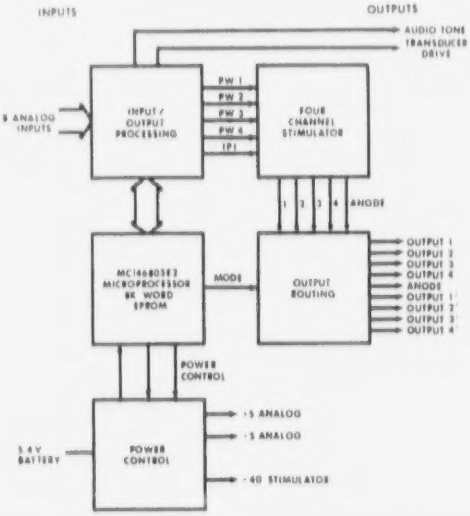

Figure 1. FES System Functional Block Diagram.

The microprocessor section utilizes the input signals to control the outputs as dictated by the software control algorithm. The microprocessor is a CMOS Motorola MC146805E2. It has sixteen input/output lines, an eight bit programmable timer and 112 bytes of RAM. The microprocessor can utilize up to 8K words of program storage in the form of a single 64K bit EPROM (27C64). The microprocessor controls the two eight channel input and output multiplexers as well as an eight bit digital to analog converter. Two digital lines are used to control power of both the stimulator board and analog circuitry.

The stimulator section is a slightly modified version of the stimulator board used in our earlier two systems. It is a four channel, sequential, constant current, biphasic stimulator. The output current can be manually fixed from 0 to 25 mA. The four pulse widths have a range of 0 to 250 usec with approximately a 1 usec resolution. The interpulse interval common to all four channels has a range of 100 to 15 msec. The PW and IPI can all be varied independently of each other. Five of the eight analog outputs which are generated by the microprocessor are used to control these stimulus parameters.

In order to expand the number of available stimulator output channels, a "pseudo" eight channel stimulator has been implemented through a simple output routing scheme. This is accomplished simply by a four pole double throw latching relay. While it does not provide a true eight channel stimulator, it does provide a user selectable dual four channel stimulator. The four output channels can be connected to one of two sets of four electrodes. This is a sufficent number of channels required to accomplish each grasp (6).

Software

The operating characteristics of the FES system are defined in software. Software is responsible for input conversion and signal conditioning, the user control algorithm, and control of the stimulator output. Up to 8K words of program memory are available.

The eight analog input signals are converted by software successive approximation analog to digital conversion at a 20 msec sampling interval. This technique provides a minimal hardware realization since it makes use of the DAC thus eliminating the need for a separate ADC circuit. If necessary, digital filtering and/or pure delay can be achieved.

The control algorithm provides the user with a simple means of controlling the system. Several control algorithms to date have been realized, including those used in our previous systems. A typical algorithm is given later.

Control of the stimulus parameters is accomplished through five analog voltage signals. These signals are generated by the microprocessor through the use of indexed lookup tables. A 256 entry lookup table for each parameter (four PW and one IPI) is used. The index into the table is a function of the command signal. This simple, yet powerful technique, allows each of the parameters to be varied independently in any fashion within its range as a function of some command signal. The "pseudo" eight channel system simply uses two sets of parameter lookup tables for each mode of operation.

Software development is carried out on one of our laboritory DEC LSI 11/23 minicomputer systems. A cross assembler generates op codes for the microprocessor. A PROM programmer is used to "burn" system software into the program EPROM.

System Set-Up

The investigator initially determines the stimulus regimes for each of the two grasps and the control algorithm using the laboratory computer controlled stimulation system. This simulated functional system is then evaluated for the particular individual.

Set-up of portable system requires that the electrode positions for the electrode cable be programmed via jumpers. The control algorithm to be used is loaded with parameters such as delays, left or right shoulder for control, axis of proportional control, etc. The algorithm is then assembled and an object code generated. Parameter lookup table determined by the laboratory system (7) are transformed and linked to the object code file. An EPROM is then "burned" with the control program. This EPROM is plugged into the FES system and the system becomes functional. Some trimming of input gains may be required, but otherwise the system is ready to be used. Major changes only require the generation of a new program EPROM.

System Operation

The portable FES system consists of three basic components. They are the electronics package, input transducers and cable (usually a two axis shoulder position transducer and chest switch), and electrode cable consisting of up to three percutaneous electrode site connectors and an anode.

Typical system operation might be as follows: first the electrode cable is connected to the electrode sites and the anode is attached. The transducer is also attached to the chest and shoulder. These cables and transducers are worn beneath the user's clothing. The small electronics package is placed in a convenient position such as between the individual and the armrest of the wheelchair. The transducer cable is connected first since it determines the operating mode as described later. The electrode cable is then connected which powers the system up in an idle mode. The idle mode is a low current consumption state. To functionally operate the system, the user depresses the chest switch. The system goes into a grasp mode selection scan in which audio tones of one and then two short tones indicate which grasp mode will be controlled. Releasing the chest switch will stop the scanning in the desired grasp mode. A short delay (approximately 3-5 seconds) allows the user to position his shoulder at the set point he desires. After the delay the system will turn on in a functional mode with the defined set point. Shoulder movements from the setpoint will, in turn, proportionally control the selected grasp. As in the earlier proportional system, rapid movement along the axis orthogonal to the proportional axis will initiate a hold mode which will maintain a stimulus independent of shoulder motion. Audio cues indicate the state of operation to the user.

With earlier stimulation systems we provided a separate exercise stimulator. The microprocessor based system ideally lends itself to serve both as an exercise system as well as a functional system. Again, more complex exercise algorithms may be implemented because it lacks the hardware limitations of even our most sophisticated discrete hardware exercise stimulators.

When the stimulator cable is plugged in without the transducer cable connected the device operates in an exercise mode. The exercise algorithm allows the grasp to be ramped open, closed and held at particular values. It can also cycle from a mode 1 grasp to a mode 2 grasp and turn on and off in preset time cycles. The exercise mode is used to build muscle strength and fatigue resistance.

DISCUSSION

The microprocessor based portable functional electrical stimulation system has provided us with a functionally more powerful system, while at the same time simplifying fabrication and set up. With the previous two systems much time was spent in hardware fabrication due to variations in the user control algorithm. These systems could not be built until an initial evaluation was carried out by the investigators. The microprocessor based FES system on the other hand is more "generalized" in its hardware design and its operating characteristics are programmed through software. This allows fabrication and stocking of these systems, which decreases the turnaround time required to have a person using his individualized system on a regular basis.

The microprocessor based system is much more flexible due to its increased number of inputs and outputs, as well as its ability to generate more complex stimulus patterns. It is this input/output flexibility which has allowed us to implement more diversified control schemes as well as those used in the previous FES systems. Application need not be restricted to upper extremity hand grasp systems, as were the previous devices.

The stimulus regime in the earlier stimulation systems was limited to linear pulse modulation between two end points as well as PW and IPI modulation region restrictions. The use of parameter lookup tables allows virtually any modulation scheme within the parameter ranges of the stimulator. We now implement a technique of piecewise linear approximations of nonlinear command/stimulus parameter transfer functions with our laboratory stimulation system. This development enables us to compensate for the nonlinear gain characteristcs encountered with virtually every electrode type (8). The use of lookup tables allows this technique to be realized with the portable system.

Transfer of stimulator PW and IPI parameters from the laboratory stimulation system to the portable system are done transparently. Work is now underway to make the transfer of control algorithms transparent as well. The goal is to minimize the effort required to characterize the system. It should be accomplished by the investigator through a simple menu type display on the laboratory system, thus taking the burden of setup from the hardware and software engineers.

The system electronics are housed in a 5 X 8 X 14 cm enclosure with a weight of 450 grams. Power is supplied from two 5.4 volt mercury batteries (type 134) connected in parallel. The life expectancy of the batteries is approximately 6-8 weeks. Current consumption is less than 8 mA with all channels stimulating at PWs of 100 usec and an IPI of 80 msec.

To date three of these FES systems have recieved approximately 300 device-hours of field usage.

REFERENCES

1. Peckham, P.H., Marsolais, E.B., and Mortimer, J.T. "Restoration of Key Grip and Release in the C6 Quadriplegic Through Functional Electrical Stimulation". J. Hand Surg., Vol. 5, No. 5, 462-469, 1980.

2. Peckham, P.H., Mortimer, J.T., and Marsolais, E.B. "Controlled Prehension and Release in the C5 Quadriplegic Elicited by Functional Electrical Stimulation of the Paralyzed Forearm Musculature". In Print, Annals of BME, Vol. 8, No. 4, 1981.

3. Strother, R., Buckett, J., and Peckham, P.H. "A Functional Neuromuscular Stimulation System for Control of Grasp and Release". Proc. of 4th Annual Conf. on Rehab. Eng., Washington, D.C., 1981, pp. 223-225.

4. 4th Annual Progress Report - Rehabilitation Engineering Center at Case Western Reserve University, Cleveland, Ohio, May, 1980 to April, 1981.

5. Buckett, J.R., Peckham, P.H., and Strother, R.B. "Shoulder Position Control: An Alternative Control Technique for Motion Impaired Individuals". Proceedings of International Conference on Rehabilitation Engineering, Toronto, 244-247, June, 1980.

6. Peckham, P.H., Thrope, G.B., Buckett, J.R., Freehafer, A.A., and Keith, M.W. "Coordinated Two Mode Grasp in the Quadriplegic Initiated by Functional Neuromuscular Stimulation". IFAC Symposium, 7th Midwest Biomedical Engineering Conference, Ohio State University, Columbus, Ohio, May, 1982.

7. Thrope, G., Peckham, P.H., and Crago, P. "A Computer Controller Multichannel Stimulator for Laboratory Use in Functional Electrical Stimulation". Proc. of 4th Annual Conference on Rehab. Eng., Wash., D.C., 1981, pp. 220-222.

8. Crago, P.E., Peckham, P.H., and Thrope, G.B. "Modulation of Muscle Force by Recruitment During Intramuscular Stimulation". IEEE Transactions on Biomedical Engineering, Vol. BME-27, No. 12, December, 1980.

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Correspondence should be sent to J. R. Buckett, Case Western Reserve University Rehabilitation Engineering Center, Cleveland Metropolitan Highland View Hospital, 3395 Scranton Road, Cleveland, Ohio, 44109.

STUDIES IN FUNCTIONAL ELECTRICAL STIMULATION FOR STANDING AND FORWARD PROGRESSION

R. J. Jaeger and A. Kralj*
Pritzker Institute of Medical Engineering
Illinois Institute of Technology
*Faculty of Electrical Engineering
Edvard Kardelj University, Ljubljana, Yugoslavia

ABSTRACT

The use of Functional Electrical Stimulation (FES) is considered to have great potential to restore some degree of useful movement to the lower extremities in paraplegia. We have approached this issue from the point of view that the simplest possible surface stimulation system be developed which will be useful in accomplishing the activities of daily living and allow rapid evaluation of the technique in a number of individuals. Our preliminary experiments have been performed on six individuals. The results indicate a number of limitations for a surface stimulation system. Nevertheless, for some individuals, such a system may be appropriate, either as a supplement to or replacement for conventional bracing technology. Two psychosocial issues regarding the use of FES are also discussed.

INTRODUCTION

The use of FES for standing and forward progression in paraplegia resulting from complete spinal cord injury has been investigated in a number of laboratories. The most prominent work has come from the Rehabilitation Engineering Center in Ljubljana, Yugoslavia (1,2). This paper deals with similar work accomplished during the first year in a new research program at the Pritzker Institute of Medical Engineering.

BACKGROUND

Standing

The use of FES for standing is a prerequisite for using FES for forward progression. In theory standing by FES would require bilateral stimulation of hip, knee and ankle extensors. However, in practice, standing requires bilateral stimulation of the quadriceps. This is the minimum requirement. The hip joint may be locked by natural ligamentous means when the proper "C" curve posture is assumed. This is the same technique utilized by persons with conventional braces. Balance and stability are obtained by using the upper extremities and balance aids, such as parallel bars or walkers. The ankle joint is unstable or only weakly stabilized by the "spasticity" or tightness of the *triceps surae* which is present in many paraplegics. There have been numerous reports on the effect of various types of electrical stimulation on "spasticity" (3). It is possible FES of the quadriceps might in some as yet unknown way cause significant alterations in the "spasticity" of ankle plantarflexors, or other muscle groups. Preliminary data show that alterations of ankle compliance can occur (4). Whether these alterations will become a problem when FES is used for standing or forward progression remains to be seen.

There are currently six subjects in our program able to stand with varying degrees of success by FES. Three subjects stand reasonably well with some support for balance. Three others have some problems with hip contracture and unwanted spasms.

A stimulator has been constructed for standing which is similar to one in use at the REC in Ljubljana (5). The operation of the stimulator is shown in figure 1. The maximum stimulating voltage is preset on two potentiometers, while the patient is sitting. After pushing a button to indicate a postural change is desired, a two second delay is provided to allow the subject to position his hands prior to standing. Then a brief auditory tone is provided and stimulation begins at pulse width of 0.002 msec and increases to 0.4 msec in a nearly linear manner over a two second period. Stimulation is then maintained until the postural change button is again pressed. A two second delay is followed by a tone indicating the beginning of the ramp-down of the stimulus pulse width.

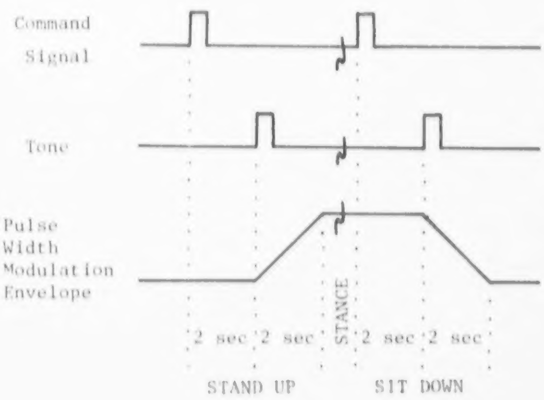


FIGURE 1

The subjects who have used the stimulator for standing in the laboratory have expressed satisfaction with the time delays and auditory feedback. During the coming year we will attempt to evaluate the potential impact of standing at home by FES on the activities of daily living.

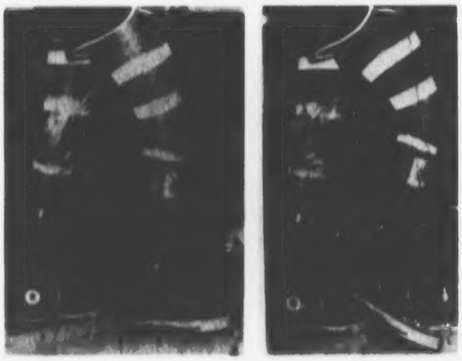
Forward Progression

Once standing has been achieved by FES, the question of how best to use FES for forward progression can be addressed. One solution to this problem is to directly stimulate over various muscles or their motor nerves in the appropriate sequence to obtain the swing phase of gait. This approach had its origin in the peroneal brace for foot drop in stroke (1). In paraplegia there is no function of hip flexors and it is not possible to stimulate these muscles directly from the surface. Since functional hip flexors are crucial for the swing phase in spinal cord injury, another method must be used.

In spinal cord injury, loss of descending inhibition unmasks the flexion withdrawal reflex to the point where it can be readily elicited by appropriate stimulation at several points (6). In the flexion withdrawal reflex, one channel of stimulation activates a number of muscle groups. The relationship between reflex stimulation and resulting reflex movement is much more complex than the relationship between direct stimulation over a muscle and the resulting contraction. Previously reported data has shown habituation of the response over time (2).

In our attempts to utilize the flexion reflex we have observed the following. There is sometimes large intersession variability in the response, even when every attempt is made to correctly position the surface electrodes. On some days, we have been able to obtain the response by stimulating simultaneously at two sites, the usual peroneal nerve site and the saphenous nerve.

We have also observed inappropriate contraction of the soleus muscle in two individuals. In one of these individuals, we obtained stronger flexion reflex responses with increasing stimulation voltage at the peroneal nerve. At some point, further increases in voltage continue to increase reflex activation of hip flexors, but begin activating the ankle plantarflexors. The desired response is achieved only by very careful adjustment of the stimulating voltage. This is shown in figure 2.

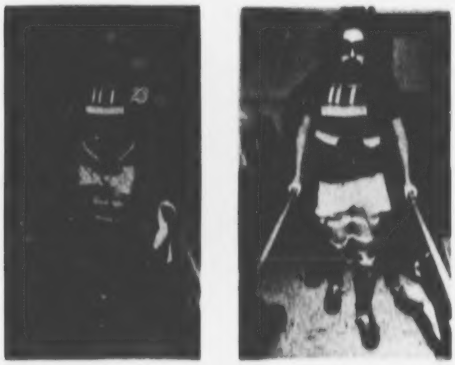


CORRECT STIMULATION   EXCESSIVE STIMULATION

FIGURE 2

We have observed scissoring in the FES enabled gait in two of our subjects. We feel this is due to the on-off alternating nature of flexion reflex and quadriceps stimulation, the abruptness of which appears to trigger activity in hip adductors. This has been previously reported, and could be corrected with stimulation of hip abductors (1). In attempting to avoid adding an additional channel of stimulation, we have had some success in solving the the problem by providing a delay of approximately 200 ms in the stimulation sequence between termination of flexion reflex stimulation and onset of quadriceps stimulation. When the flexion reflex stimulation is terminated there is a period when no stimulation is occuring in the limb, allowing it to fall under the influence of gravity and segmental reflex mechanisms which can prevent scissoring. This is shown in figure 3, which compares the third step in two sequences of forward progression.

Pushbuttons have been used to actuate flexion reflex stimulation and terminate quadriceps stimulation during gait. Typically, the therapist controls the pushbuttons, but pushbuttons on walker handles or crutches have also been used with success (2). Since most of our work has been done with the parallel bars as balance supports, we have tried pushbuttons in the hands of the experimenter, but have been more successful when subjects have worn pushbuttons or membrane switches on their fingertips, with the aid of plastic rings and velcro. This allows the subject to better coordinate his upper body movements with the actuation of the flexion reflex.



WITHOUT DELAY

WITH DELAY

FIGURE 3

Psychosocial Aspects

One of the areas we have attempted to address has to do with the general issue of the psychosocial impact of advanced technological research on disabled individuals who are participating as subjects. We are particularly concerned with two issues: obtaining informed consent and dealing with unrealistic expectations. Standing and walking are very emotional topics for the paraplegic. We are trying to determine what must be done beyond normal informed consent procedures to make sure that subjects truly understand the research and their role in it. Methods must be developed to assess expectations of subjects. Our preliminary experience suggests that in depth interviews are necessary. The research team must frequently work with subjects so that realistic expectations concerning the outcome of their participation in the research are maintained, and dissapointment with lack of progress can be eased.

REFERENCES

(1) Vodovnik, L. et al. Functional Electrical Stimulation for Control of Locomotor Systems. CRC Critical Reviews in Bioengineering 6:63-131, 1961.
(2) Kralj, A. Ljubljana Rehabilitation Engineering Center Research Project Annual Progress Report #3, 1961.
(3) Dimitrijevic, M. and Sherwood, A. Spasticity: Medical and Surgical Treatment. Neurology 30:19-27,1960.
(4) Jaeger, R. and Kralj, A. Functional Electrical Stimulation Changes Joint Compliance. Proceedings of the 5th Annual Conference on Rehabilitation Engineering, Houston TX, p.55,1962.
(5) Bajd, T. et al. Use of a two channel functional electrical stimulator to stand paraplegic Patients. Physical Therapy 6:526-527, 1961.
(6) Lee, K. and Johnson, R. Electrically Induced Flexion Reflex in Gait Training of Hemiplegic Patients: Induction of the Flexion Reflex. Archives of Physical Medicine and Rehabilitation 57:311-314,1976.

ACKNOWLEDGEMENTS

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ADDRESS

Robert Jaeger, Ph.D.
Assistant Professor
Pritzker Institute of Medical
Engineering
Illinois Institute of Technology, E1-125
Chicago, IL 60616

3.7

Reciprocal Walking in Paraplegic Patients Using Internal Functional Electrical Stimulation

E.B. Marsolais, Rudi Kobetic, G.F. Cochoff, P.H. Peckham
Veterans Administration Medical Center, Cleveland, Ohio

Reciprocal walking appears to be the most cosmetic and energy efficient method of ambulation for the paraplegic patient. The advent of functional electrical stimulation with microprocessor control and intramuscular electrodes made achievement of this goal possible in selected patients.

Kralj first reported on the use of functional electrical stimulation to create reciprocal walking in 1980 (1). He used external electrodes and achieved hip flexion through a reflex action. The patients were able to walk using parallel bars for balance and support during weight transfer. The stimulation was controlled by preset timers. Since then, one patient was able to walk using a wheeled walker (2). We have reported on the ability to make selected partially paralyzed non-walking patients walk using timers for control of functional electrical stimulation and implanted electrodes (3). In this communication, we will review our experience in producing reciprocal walking in the complete paraplegic patient using a portable microprocessor controlled stimulator for electrical stimulation and intramuscular percutaneous electrodes. Currently, one patient is able to walk in parallel bars or with a walker, while three others are in various stages of being implanted and are undergoing an excercise program.

Materials and Methods

Patients included in this study had complete lesions from T4 to T12 with no significant peripheral nerve damage. They were able to walk three meters using long leg braces in a swing to or swing thru gait with the assistance of one person. No other major medical or emotional problems were noted. Subjects meeting the basic criteria on history were given a physical examination and an electrical assessment was made on the availability of innervated muscles for implantation.

The intramuscular electrode was made from a 45 um multistrand stainless steel wire coated with Teflon which was deinsulated at the end and wound over a .15mm mandril. Approximately 10mm of the coil and a hook were deinsulated at the end of the electrode. The electrode was placed in a 19 gauge hypodermic needle for implantation upon which the needle was removed and the electrode remained in the muscle (4). The intramuscular electrode was stimulated cathodically with constant current pulses up to 20 mA in amplitude, 150 usec in pulse width, and 50 Hz in frequency. The anodic reference electrode was a pregelled, disposable, silver/silver chloride ECG electrode (C.R. Bard Inc., Lombard, Il).

A preset stimulation pattern was based on the normal activity of the muscles and on our previous experience with the stimulation of paralyzed muscle (3). The projected pattern was evaluated with our laboratory stimulator controlled by the MINC 11/23 using software modified from the Upper Extremity Stimulation Project. The final workable pattern, Fig. 1, was then transferred into the Erasable Programmable Read Only Memory (EPROM) of the portable microprocessor controlled patient stimulator. The input command which enabled the patient to proceed through the stimulation pattern was controlled by two push button switches. The first switch indicated the readiness of the patient and the second switch initiated the stimulation. The processor halted the pattern at two stops; the first, at 35%, allowed the time for transferring of weight to the left leg, and the second stop at 65% allowed transfer of weight to the right leg. The processor proceeded through the pattern at the approximate speed of 1 sec/10% and remained at the stop until further command. The stimulus parameters included a constant interpulse interval and a pulse width modulated from 0 to 150 usec to control the force of muscle contraction. This is indicated in figure 1.

Good reliable contraction was achieved by first using a 25 gauge probe needle to locate the maximal response of the muscle to electrical stimulation. An intramuscular electrode was then implanted which matched the response of the probe. Two body entry points were selected bilaterally to provide access to the desired muscles. The first entry point was made approximately half way between the knee and the hip, on the medial aspect of the thigh, to provide access to quadriceps, sartorious, tensor, all adductors and hamstrings, and soleus-gastrocnemius group. The second entry point was made just medial to the anterior superior spine of the iliac crest for access to the iliopsoas and gluteal muscles. Strong reliable contractions of quadriceps muscles were first achieved with at least one electrode in each muscle head. The iliopsoas was then investigated for hip flexion and if not reasonable, the tensor and sartorious were implanted. The anterior part of adductor magnus was implanted to balance the external rotation and abduction produced by sartorious and tensor, respectivelly. The posterior portion of the adductor magnus was implanted for hip extension. The soleus was implanted for plantar flexion. The exercise program was initiated 2 weeks post implantation to allow stabilization of electrodes and to minimize their movement.

Results

Our walking patient was a 24 year old male. He developed a traumatic complete paralysis at the T8 level when he was injured by a gunshot in February of 1982. We began implantation of his

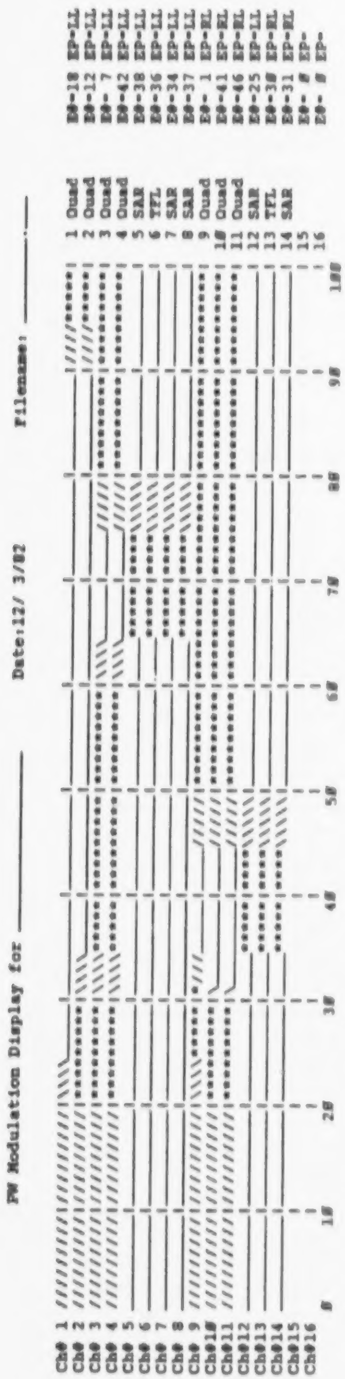

FIGURE 1: Standing and Gait Cycle Stimulation Pattern

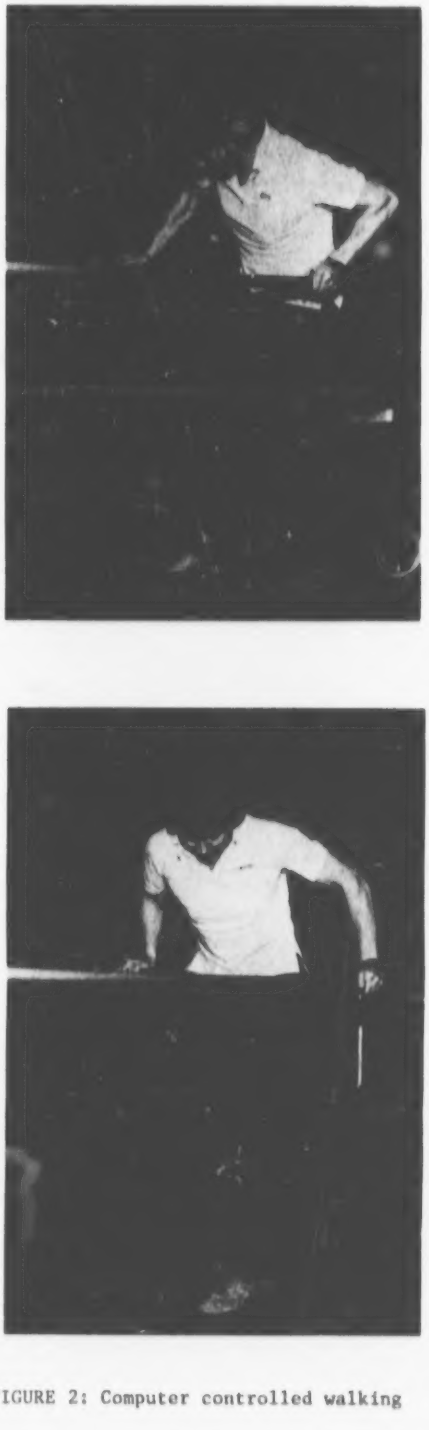

FIGURE 2: Computer controlled walking

electrodes in August of 1982. He had 25 electrodes including: 2 in the vastus medialis, 2 in the vastus lateralis, 1 in the vastus intermedius, 3 in the sartorius, 2 in the tensor, and 2 in adductor magnus, bilaterally. One electrode was implanted in the soleus muscle of the left leg. This patient was able to get up from his wheelchair and walk without assistance in parallel bars, Fig. 2, or with a walker using a 14-channel portable microprocessor controlled stimulator. He stood up by activating two electrodes in each Vastus Medialis and Vastus Lateralis, bilaterally, and used his arms for additional strength and balance. After first shifting his weight onto his left leg using his arms and maneuvering his upper body, he activates electrodes in the right sartorious and tensor to achieve hip flexion followed by stimulation of the quadriceps to bring the foot forward and complete the step. Upon transferring the weight to the right leg he activated the left leg for the forward progression, and the cycle repeated.

The other three patients range in age from 26 to 29 and in level from T4 to T7. One is ready to begin walking and one is just beginning implantation.

Discussion

This work demonstrates that it is possible to achieve reciprocal walking in a patient with complete paraplegia utilizing implanted percutaneous electrodes under computer control and a standard walker. Strong, selective, and reproducible contractions are available to the patient through intramuscular electrodes. Since the patient needs only to plug in a small connector, donning the device is much simpler than using external surface stimulation, which requires specific positioning of electrodes. The system is simple enough so that patient can use it outside the laboratory.

The results also demonstrate that electrically induced gait is achievable with an open loop control, but it does not rule out the future need for closed loop control to provide better stability. Our plans include exploration of various sensors and adaptive closed loop controllers to improve electrically augmented gait. An expansion to 32 channels of stimulation will be implemented to allow stimulation of hip extensors, abductors and adductors to improve stability, cosmesis and to reduce energy consumption.

ACKNOWLEDGEMENTS

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BIBLIOGRAPHY

(1) Kralj, A., Bajd, T., and Turk, R.: Electrical stimulation providing functional use of paraplegic patient muscles. Med. Prog. Technol. 7:3, 1980.

(2) Kralj, A.: Personal communication, 1982.

(3) Marsolais, E.B., and Kobetic, R.:Functional Walking in Paralyzed Patients by means of Electrical Stimulation. Clin. Ortho. in press.

(4) Caldwell, C.W., and Reswick, J.B.: A Percutaneous Wire Electrode for Chronic Research Use. IEEE Conf. Proc., 1981, p. 206.

E.B. Marsolais, M.D., Ph.D.
Veterans Administration Medical Center
10701 East Blvd.
Cleveland OH 44106

IMPLANTABLE MUSCLE STIMULATORS FOR BONE GROWTH STUDIES

R.W. Vreeland, PE, CCE, E.P. Harvold, DDS, PhD,
G. Chierici, DDS, and A.J. Miller, PhD

University of California, San Francisco

Investigation of factors affecting bone growth has been in progress for more than ten years (1).

Studies at the Center for Craniofacial Anomalies here have utilized radio frequency coupled telestimulators implanted in rhesus monkeys (2). The monkey is prepared with two bone grafts; one on each side of the head under the tendon of the temporalis muscle. Stainless steel screw-in electrodes are implanted in the temporalis muscle on one side of the head only. The stimulator is implanted under the skin of the monkey's back. It is connected to the electrodes via bipolar pacemaker catheter. The muscle on the other side of the head is not stimulated and serves as an experimental control. A sixty watt output transmitter mounted on top of the monkey cage (Fig. 1) controls the stimulator implant. The transmitting antenna is an inductively loaded dipole mounted inside the PVC pipe in the center of the cage. Transmitter keying is done by a laboratory stimulator (not shown). The width of the stimulator pulse and the pulse repetition rate are determined by the laboratory stimulator. We have found this method of stimulation to be very useful for determining the experimental parameters. It does, however, require a specially instrumented monkey cage.

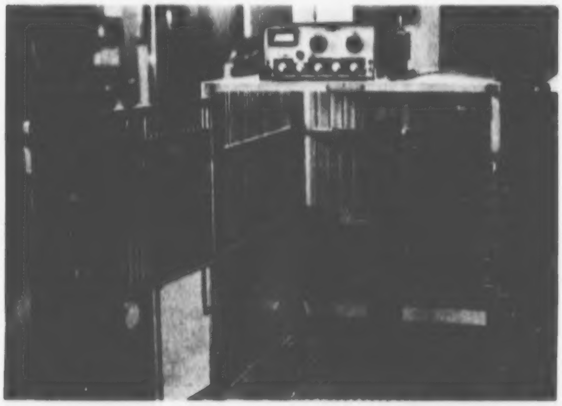

Fig. 1. A monkey cage instrumented for radio telestimulation. The transmitting antenna is inside the polyvinyl chloride pipe in the center of the cage.

Once the optimum pulse width and repetition rate had been established, we built fixed rate free running implantable stimulators. We have two models. One delivers a single 1.5 millisecond pulse every five seconds. The other delivers a 1.5 millisecond pulse every three seconds. These units are powered by a 3.9 volt lithium cell with an estimated battery life of three years. A normal experimental run is two to four months.

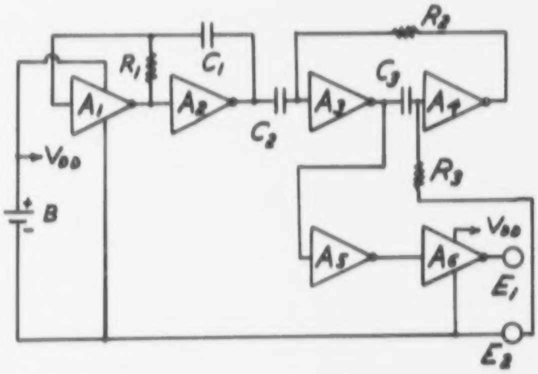

Fig. 2. The circuit used for the three second and five second period free running implants. C1=0.22 mfd. C2 and C3=0.1 mfd. R1=7.5 meg for a three second period and 12 meg for a five second period. R2 and R3=10K. Screw in electrodes E1 and E2 are implanted in the temporalis muscle.

The same circuit (Fig. 2) is used for both models. It consists of a clock (A1 and A2) for determining the pulse spacing and a one-shot (A3 and A4) which establishes the pulse width. These circuits were described by Dean of RCA in 1970 (3). We use a Motorola MC14069U hex inverter for A1, A2, A3, A4 and A5. Inverter A3 consists of two inverters connected in parallel. A plastic case dual in line inverter package was chosen because it provides sturdy terminals for mounting the smaller components. No printed circuit board is needed. In order to drive our relatively low impedance screw-in electrodes (E1 and E2), a low impedance driver (A6) is required. We use an RCA CD4049AD hex inverter with all six inverters connected in parallel. This circuit will deliver about two volts into a 330 ohm load. The battery (B) is a single 3.9 volt 3B50 lithium cell manufactured by Electrochem (4). It is rated at one ampere hour and is hermetically sealed. We estimate that it will run the implant for three years assuming 0.7 ampere hour capacity for a useful minimum voltage of 3.2 volts. This, of course, is based on the assumption that the implant will not be damaged by moisture leakage. We use a mixture of half beeswax and half paraffin as a moisture barrier.

For our more recent studies we are using free running stimulator implants with pulse-to-pulse intervals of one, two or three minutes and a pulse width of about two milliseconds. Accomplishing this would have required excessively large values of R1 and C1 if we had used the circuit of Fig. 2. We, therefore, decided to use the circuit shown in Fig. 3. It employs an Intersil ICM7556IPD dual CMOS timer. The lefthand timer (Fig. 3) is a clock, the frequency of which is determined by R1 and C1. For a one minute stimulus pulse-to-pulse interval it runs at 6.6 Hz. The square wave clock signal is differentiated by C2 and R2. A 1N484B diode (D) selects only the positive differentiated pulses. These pulses charge C3 through R3 until the trip level of the righthand timer is reached.

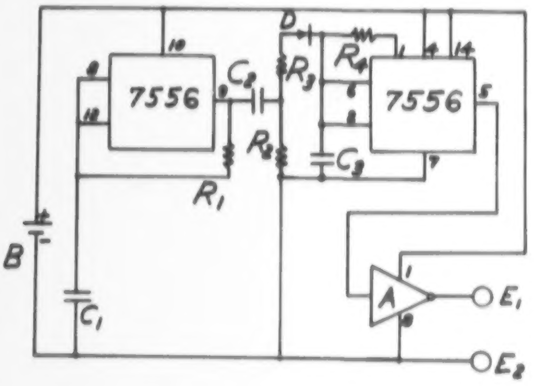

Fig. 3. An extremely low duty stimulator. C1=0.22 mfd, C2=0.033 mfd and R2=15K

Pulse-to-Pulse Interval	C3	R1	R3	R4
1 min.	0.1 mfd	470K	375K	27K
2 min.	0.22 mfd	330K	295K	12K
3 min.	0.22 mfd	1 meg	135K	12K

A field effect transistor inside the 7556 then dumps C3 through R4. The C3, R4 time constant determines the two millisecond pulse width. The pulse-to-pulse interval is determined by the R3, C3 time constant. Our electrode driver (A) is a CD4049AD with all six inverters connected in parallel. The battery (B) is an Electrochem 3B50 lithium cell. The one minute unit draws 120 microamperes, thereby limiting the useful battery life to an estimated eight months. We estimate a battery life of a year to a year and a half for two minute and three minute stimulators.

We have used a variation on this circuit (Fig. 4) as a burst generator intended for brain stimulation. Two of the inverters from a CD4049AD (A1 and A2) are used as a clock. The clock circuit is basically the same as in fig. 2, except that its repetition rate is thirty pulses per second. After being differentiated by C2 and R2 (Fig. 4) the positive going pulses charge C3 through R3. This time constant was chosen so that C3 would charge up to the dumping threshold in sixty seconds. Capacitor C3 is then dumped through R4 in ten seconds. The result is a train of ten second pulses with a one minute repetition period. These pulses are inverted by A3 and used to enable the other 7556 which gates the 30PPS clock pulse train. The time constant of C2 and R2 was chosen so that the width of the pulses at the output of the 7556 gate would be 500 microseconds. Inverter A4 consists of three inverters from the CD4049AD connected in parallel. The output waveform is a ten second burst of 500 microsecond pulses with a pulse repetition frequency of 30 Hz. These bursts are repeated at one minute intervals. The duty cycle of the pulses within the burst is high enough to produce a significant DC component.

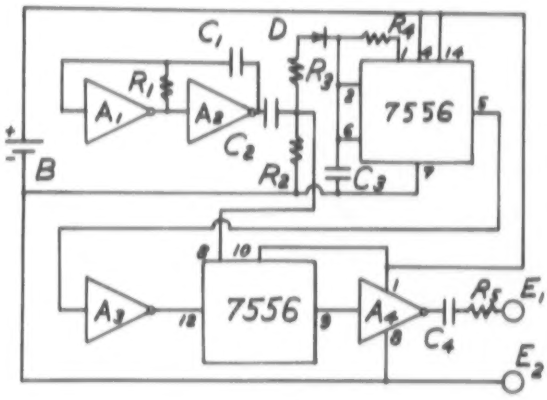

Fig. 4. A burst stimulator consisting of two dual in line integrated circuits. R1=62K, R2=15K, R3=330K and R4=15 Meg, C1=0.22 mfd, C2=0.033 mfd, C3=0.68 mfd, and C4=0.68 mfd. The diode D is a 1N484B. An Electrochem 3B50 lithium cell provides 3.9 volts of battery power and an estimated useful life of five months. The inverters A1, A2, A3 and A4 are in an RCA CD4049AD.

This DC component is removed by capacitor C4. The current required for brain stimulation is significantly smaller than that required for muscle stimulation. A resistor (R5) is selected to limit the stimulus current to the desired value.

RESULTS

Stimulation with a three second pulse-to-pulse interval clearly disrupts bone growth at the graft under the tendon of the stimulated muscle. Pulsing with a five second pulse spacing also appears to have an affect. We do not yet have significant data for the one, two or three minute intervals.

When the graft on one side of the head is stimulated with a three second pulse-to-pulse interval, there has actually been increased bone growth at the unstimulated control graft on the opposite side of the head. This affect has been clearly demonstrated.

DISCUSSION

The circuit shown in fig. 4 requires only two dual in line integrated circuits. Its design is somewhat critical, however, because of the dual functions of the R2, C2 and R3, C3 time constants.

Because of the very low duty cycles, no output blocking capacitors are required in the circuits shown in fig. 2 and fig. 3.

When designing implants, it is desirable to avoid the use of very high resistor values which might be degraded by moisture leakage. It is especially important to wax coat the implant with a fifty-fifty mixture of paraffin and beeswax before applying the Silastic outer coating. A

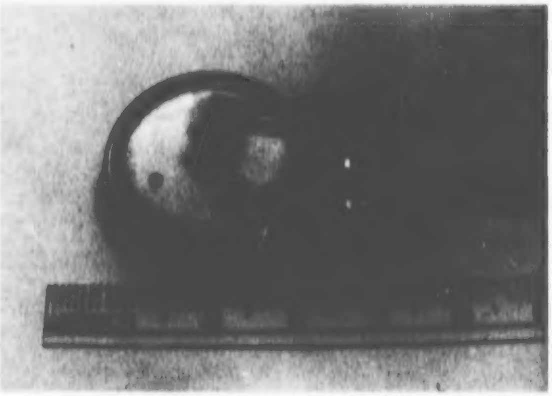

Fig. 5. A completed implant ready for encapsulation. The battery is a 3.9 volt lithium cell. Two dual in line integrated circuit packages are used. This method of construction provides solid support for the smaller components without the necessity for a printed circuit board.

completed implant is shown in Fig. 5 before coating and in Fig. 6 after coating.

CMOS integrated circuits are interesting because they consume virtually no power except when changing states. For this reason it is desirable to use the lowest clock frequency consistent with overall circuit performance. A somewhat oversimplified analogy to a CMOS integrated circuit is shown in Fig. 7. It consists of two toggle switches connected in series across a battery. One of the switches is always open so that no current flows except to charge capacitor C which represents the input capacitance of another CMOS integrated circuit. In Fig. 7A the output is high and the capacitor has been charged by the battery. The circuit of Fig. 7B represents the output low state. There capacitor C is discharged through switch S2. Note that each time the circuit changes state capacitor C is either charged or discharged. It is this capacitor charging current that runs the batteries down. If a lower clock frequency is used the capacitor C will be charged and discharged less frequently. The result will be improved battery life.

Fig. 6. The completed implant is dipped in a fifty-fifty mixture of melted beeswax and paraffin. It is then coated with Dow Corning 3140 RTV Silastic. Some of our units which had not been wax dipped failed due to moisture leakage.

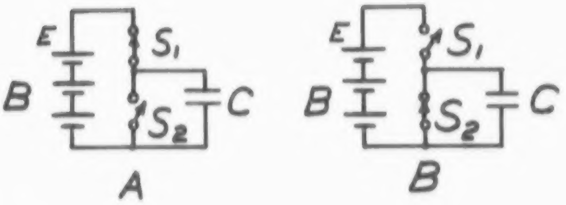

Fig. 7. A simplified analogy of a CMOS integrated circuit showing the high state (A) and the low state (B). Note that most of the battery power is used to charge capacitor C which represents the input gate of another CMOS circuit.

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REFERENCES

1. Harvold, E.P., Neuromuscular and Morphological Adaptations in Experimentally Induced Oral Respiration. In: Naso-Respiratory Function and Craniofacial Growth. (McNamera, J.A., Jr., ed.) Monograph No. 9, Craniofacial Growth Series, Center for Human Growth and Development, U. of Michigan, 1979, pp 149-164.

2. Vreeland, R.W., Harvold, E.P., Chierici, G., and Miller, A.J., A Completely Implantable Muscle Telestimulator for Monkeys, AAMI 16th Annual Meeting, Washington D.C., May 1981.

3. Dean, J.A., Astable and Monostable Oscillators Using RCA COS/MOS Digital Integrated Circuits. RCA Application Note ICAN-6267, 1970.

4. Electrochem Industries, Inc.
9990 Wehrle Drive
Clarence, New York 14031

Robert W. Vreeland
University of California
Research and Development Laboratory
Third & Parnassus Avenues, Room UB-10
San Francisco, California 94143

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SYNERGISTIC CONTROL SYSTEM FOR PARALYZED EXTREMITY JOINT

M. Solomonow, PhD and S. Burke, M.D.
Biosystems Laboratory, Department of Orthopaedic Surgery
Tulane University School of Medicine, New Orleans, Louisiana, 70126

ABSTRACT

The time and frequency responses of isometric muscle force during recruitment induced by high frequency electrical stimulation have been determined. The transfer function of the muscle during recruitment was developed and utilized in the design of a closed loop synergistic control system for a paralyzed joint.

INTRODUCTION

Direct stimulation of a muscle nerve at supramaximal levels with variation of pulse rate between the frequency of fusion (20-30 pps) to tetanic frequency (60-70 pps) was shown to provide control of the higher 20% of the total muscle force (1). Furthermore, stimulation at rates above 45 pps result in rapid muscle fatigue and loss of its force control.

In order to improve the control of the muscle so movements requiring fine to moderate forces could be provided, a stimulation technique capable to induce the recruitment of motor units according to their size could be employed. The technique consists of dual electrodes placed on the muscle nerve, with one electrode providing fused muscular contraction utilizing stimulus of suprathreshold level at 35 pps. The distal electrode delivers stimulus of 600 pps with variable amplitude. Since such high stimulation rate induces neuromuscular blockade, amplitude level near suprathreshold provide fine muscle force generated primarily by the smallest motor units. As the stimulus amplitude is reduced, moderate to large motor units escape the block and contribute to increase the muscle force (2,3,4).

The technique was shown to control 5-100% of the muscle force with no fatigue if background fused contraction was developed by stimulus rates of less than 50 pps (4).

The objective of this study is to define the frequency and time response of the muscle during such recruitment, and utilize the finding in the design of a synergistic control system. The need for a feedback mechanism could also be determined from the expected data.

METHODS

Instrumentation

Background fused contraction of the muscle was accomplished by a stimulus from a Grass Model S-4 stimulator at suprathreshold amplitude and 35 pps delivered via bipolar electrode on the sciatic nerve.

Recruitment stimulus was delivered from a stimulator design in our Laboratory. The stimulator consisted of circuits capable of generating AC signals of various amplitudes and frequencies super-imposed on a DC voltage. The composed AC-DC signal was then modulated by 100μsec pulses at a rate of 600 pps and was applied to the sciatic nerve by a second bipolar electrode.

Stimulus signal and muscle force were displayed on a four channel physiograph recorder using a myograph transducer for muscle force measurement.

Preparation

Three adult cats were tested. The cats were anesthetized by Chloralose, and the soleus muscle-sciatic nerve were prepared. The muscle was isometrically affixed to the force transducer, and the sciatic nerve branches to other muscles were cut.

Protocol

Frequency response tests were accomplished by production of background fused contraction with recruitment stimulus applied 2-3 seconds later. The recruitment stimulus AC envelope was set at 0.1 Hz with peak to peak amplitude adjust in the range between subthreshold to suprathreshold of the nerve. Two to three cycles of AC envelope were recorded for each frequency from 0.1 Hz to 6 Hz as shown in Figure 1.

Time response tests were accomplished by applying recruitment stimulus 2-3 seconds after background fused contraction was initiated. The recruitment stimulus was applied for 60 seconds allowing the force response to stabilize. Recruitment stimulus frequencies in the range of 0.1 Hz to 2 Hz were tested. A sample recording of force time response is shown in Figure 2.

RESULTS

Body plot for the average peak to peak force amplitude for the three animals tested is shown in Figure 3.

Employing DEC 2020 computer, the frequency response of all animals for various AC amplitudes and frequencies were analyzed, and the muscles recruitment model G (jw) was derived as follows

$$G(jw) = \frac{K\,(1 + .026\,jw)}{(1 + .05\,jw)^2\,(1 + .04\,jw)^2}$$

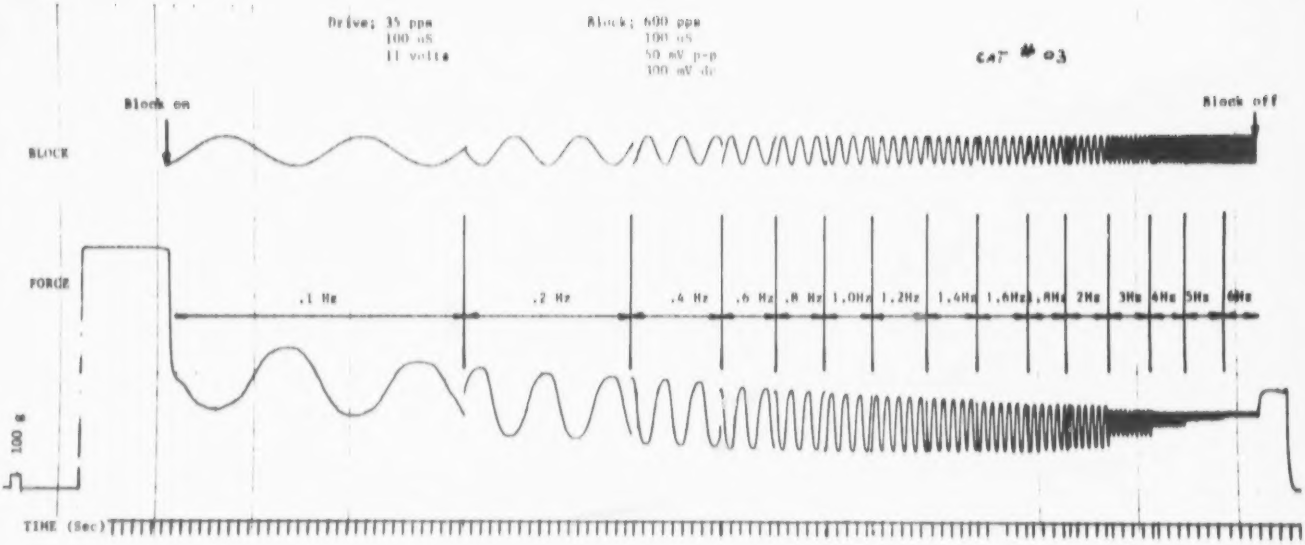


Figure 1. Force response during various recruitment frequencies (upper trace shows the recruitment AC envelope)

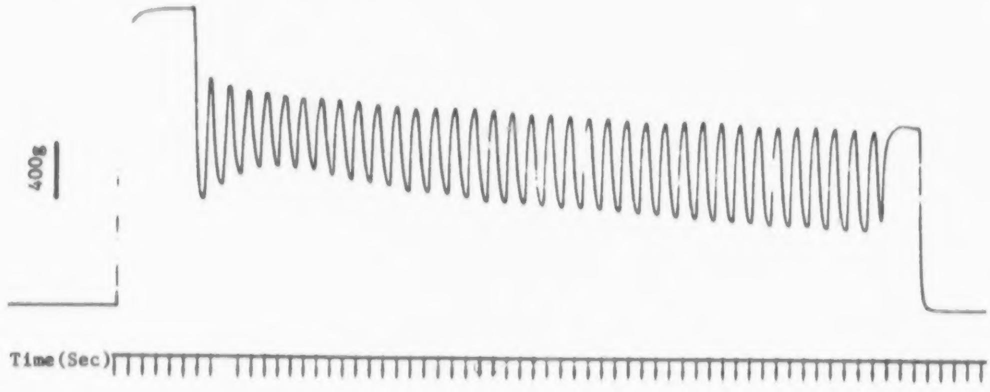


Figure 2. Force response during recruitment at .7Hz AC envelope showing the time variations during 60 Sec..

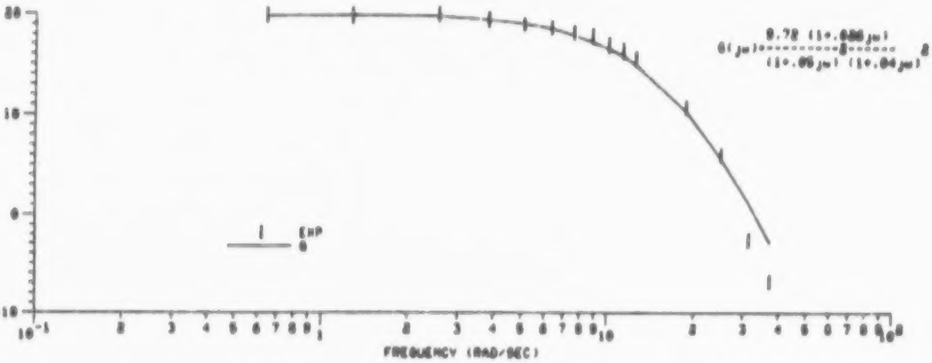


Figure 3. Body plot of force amplitude in DB as a function of recruitment AC envelope frequency.

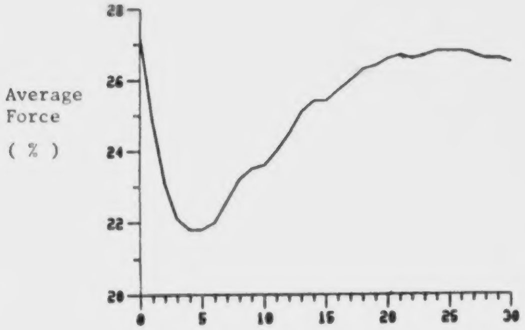
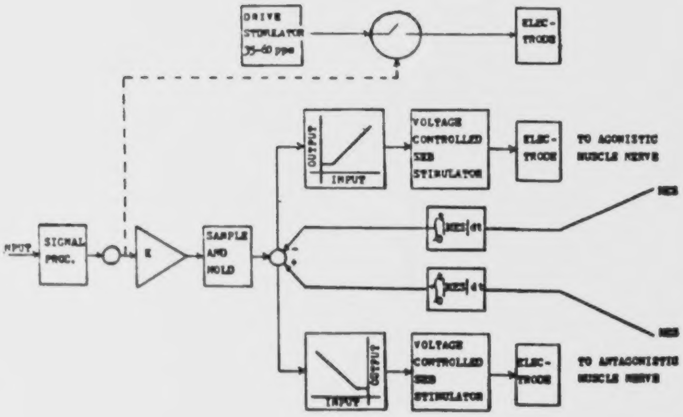


Figure 4. Average peak to peak force of test animals as a function of time.


DRIVE STIMULATOR 35-60 pps
ELEC-TRODE
INPUT
SIGNAL PROC.
K
SAMPLE AND HOLD
OUTPUT
INPUT
VOLTAGE CONTROLLED SEB STIMULATOR
ELEC-TRODE
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MES
OUTPUT
INPUT
VOLTAGE CONTROLLED SEB STIMULATOR
ELEC-TRODE
TO ANTAGONISTIC MUSCLE NERVE

Figure 5. A Synergistic control system for the control of a limb joint.

The closely spaced dual double poles demonstrate the rapid decline in response to fast movements, while movements at frequencies below 2 Hz are closely followed.

Time response analysis of all animals indicate immediate response to recruitment stimulation with an undershoot that peaks within 4-5 seconds, and a gradual recovery to the original force level within additional 15 seconds as shown in Figure 4.

The time response could be characterized therefore by an instantanious rise time, followed by some 18% undershoot peaking at 4 seconds and a settling time of 20 seconds.

CONCLUSIONS

Clearly, the time response demonstrates the need for a feedback mechanism that will improve the moderate undershoot and the relatively long settling time. The need for reduced undershoot and faster settling time is most needed during movements requiring fine force adjustment when manipulating delicate objects.

Since most practical movement are a result of combined isometric and isotonic contraction of the muscle, joint position feedback will not suffice when torque or pressure variations only are required. The myoelectric profile of a muscle does, however, indicate activity during isometric as well as isotonic contractions. It is suggested therefore to employ myoelectric feedback to improve the response and performance of the muscle during recruitment stimulation.

It is also evident that synergistic control of agonist/antagonist muscles of a muscle are required in order to provide accurate and reliable performance of the joint. Figure 5 shows a typical synergistic control system employing recruitment stimulation and incorporating myoelectric feedback.

In summary, the muscles time and frequency characteristics during recruitment type stimulation were defined and analyzed. A model of the muscle during recruitment was developed and utilized in the design of a synergistic control system incorporating myoelectric feedback. It is anticipated that such control system could provide superior performance during fine to moderate movements which include most of our daily activities such as eating, writing, dressing, etc.

REFERENCES

1. Benton, L., et al, "Functional Electrical Stimulation-A Practical Clinical Guide", page 23, Figure 5, REC, Rancho Los-Anigus, 1981

2. Tanner, J.A., "Reversible Blocking of Nerve Conduction by Alternating Current Excitation" Nature 195:712-713, 1962

3. Solomonow, M. et al, "A New Technique of Functional Neuromuscular Stimulation", Advances on External Control of Human Extremities, 1978

4. Solomonow, M., "Fatigue Optimal Selective Electroblock Parameters in the Linear Control of Paralyzed Muscle Force" Advances on External Control of Human Extremities, 1981

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M.Solomonow,PhD
Dep. of Biomedical Engineering
Tulane University
New-Orleans, LA, 70118

An Exercise Conditioning System For Paralyzed Leg Muscles

3.10P

J.A. Gruner, R.M. Glaser, S.D. Feinberg, S.R. Collins, N.S. Nussbaum and
J.S. Petrofsky. Dept. of Physiology, Wright State University School of
Medicine, Dayton, OH 45435, and Rehabilitation Institue of Ohio, Miami
Valley Hospital, Dayton, OH 45409

ABSTRACT

The purpose of this paper is to describe instrumentation and protocols in which electrical stimulation is used to induce exercise in paralyzed leg muscles. A computer controlled electrical stimulation system, using surface electrodes, automatically regulates the exercise bouts. Loads placed upon the muscles can be progressively increased over a number of training sessions in such a manner that a measure of the fitness of the legs can be obtained. With numerous exercise sessions, the strength and/or endurance of the leg muscles can be gradually and safely increased. Such exercise conditioning may provide numerous health benefits, and enable propulsion of a special vehicle via the electrically stimulated leg muscles.

INTRODUCTION

To improve the locomotive capability of individuals with paralyzed legs, a wheelchair-like vehicle which can be propelled by electrically stimulated leg muscle contractions has been constructed and successfully tested (1). Safe and effective use of such a vehicle will, however, require certain minimal performance capabilities of the paralyzed legs. Therefore the strength and endurance of the muscles to be stimulated must be evaluated and, if necessary, conditioned by exercise prior to prescription of a leg propelled vehicle (LPV).

To facilitate evaluation and exercise conditioning of paralyzed leg muscles in a clinical laboratory setting, a stationary LPV simulator would be desirable. The purpose of this project was to design and construct such an ergometer-type device which could be used for paralyzed muscle evaluation and conditioning.

BACKGROUND

In designing a conditioning program for the legs in preparation for using the LPV, endurance will be the primary consideration since the strength required to operate the vehicle should be less than 2 kg on a level surface. After several years of disuse, however, paralyzed muscles tend to convert to fast twitch type which are readily fatigued by electrical stimulation (2,3). Several studies have shown that strength and/or endurance can be increased in paralyzed muscles by electrical stimulation exercise programs (4-8). In particular, prolonged bouts of contractions of loaded muscle have been shown to cause conversion of fast twitch to slow twitch fibers. This suggests that endurance can be built in paralyzed muscle by exercise bouts of light to moderate intensity and of prolonged duration. Unfortunately, there are few studies in the literature describing instrumentation or procedures for conditioning paralyzed muscles in humans via electrical stimulation.

Preliminary studies in our laboratories have shown that sufficient leg strength can be obtained by electrical stimulation of paralyzed muscles to operate an LPV (9). However, considerable changes in blood pressure may occur during such exercise, necessitating careful monitoring (10). It has also been confirmed that both leg strength and endurance can be increased in both paraplegic and quadriplegic subjects using suitable conditioning protocols. Since the bones of paralyzed limbs are usually osteoporotic, especially where spasticity is low, care must be taken during electrical stimulation to avoid excessive stresses which might lead to bone or joint injury. This is particularly important where muscle strength is being increased by exercise, since bone strength cannot easily be evaluated in vivo, and probably will not increase as rapidly as muscle strength.

METHODS

Subjects

Several paraplegic subjects with no voluntary movement capability of their lower limbs and an absence of lower motor neuron involvement were chosen for this study. They were screened by a physician for cardiopulmonary and musculoskeletal conditions which would contraindicate participation. Screening and testing procedures were approved by the human subjects research committees of Wright State University and Miami Valley Hospital.

Leg Propelled Vehicle Simulator

The LPV simulator (Fig. 1) consists of three basic parts: 1) The framework, consisting of the ramp and backboard against which the wheelchair is positioned. 2) The "drive" system, which in this case consists of weights which are attached to the ankles via a cable and pulley system to roughly simulate the type of repetitive limb movement

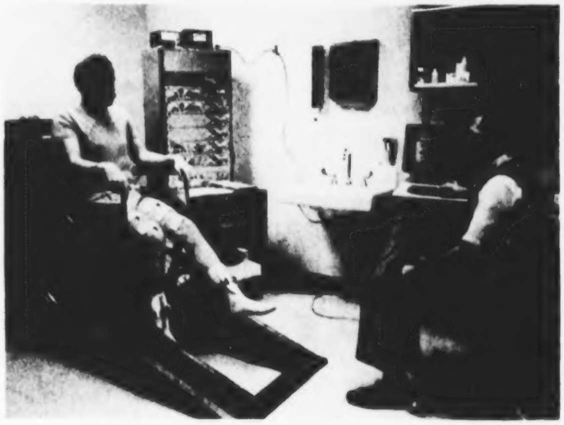

Fig. 1. Picture of the paralyzed leg conditioning system. Note subjects may be seated in their own wheelchairs during exercise.

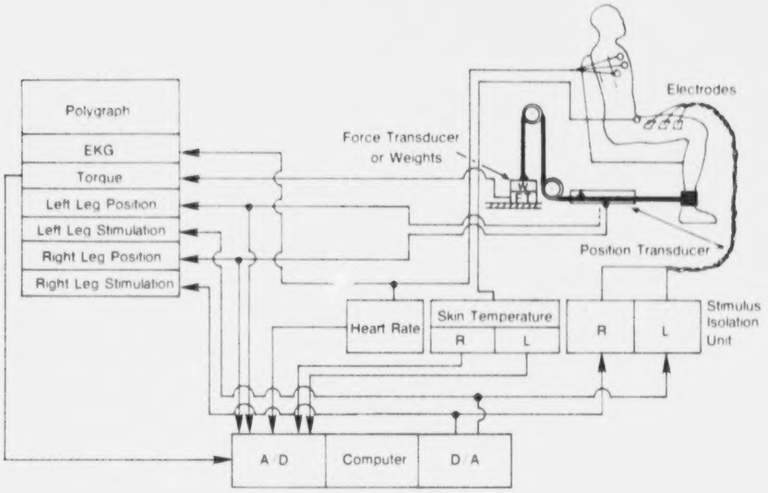

Fig. 2. Leg propelled vehicle stimulator. Subject is seated in wheelchair with ankles attached to cable and weight system. Computer-controlled stimulus isolation unit provides stimulus to appropriate muscle group through surface electodes. Heart rate, skin temperature, and leg position are monitored by the computer. The polygraph records EKG, leg position, and stimulus amplitude. A force transducer is placed in series with a cable to measure isometric leg strength and/or endurance.

required for operating the LPV. 3) The electronic instrumentation consisting of the computer, the stimulator, and feedback sensors. A schematic diagram of this system is given in Fig. 2.

Electrical Stimulation System

An Apple computer provides voltage signals to an isolated, battery powered stimulator. The stimulator delivers constant current, 200 microsecond pulses to two (cathodal) surface electrodes (3M company) (48 sq cm) located over motor points above the quadriceps muscle group. Stimulation for the two cathodes is at 30 hz per electrode and 180 degrees out of phase. A common (anodal) electrode is placed just above the kneecap of each leg. Peak current was less than 4 ma/cm^2.

A computer program which monitors leg position controls stimulation to the muscles. Leg position is determined by potentiometers driven by the weightlifting cable attached to the ankle. During operation, the computer gradually increases the stimulus amplitude until the leg extends from its resting position to the maximum desired position (PMAX), and then gradually decreases the stimulation until the leg returns to resting position. In actual operation, a trial run is first performed in which the stimulus threshold for contraction and the stimulus amplitude (SMAX) required to extend the leg to PMAX are first determined for each leg. During continuous (cyclic) operation in which the legs extend and flex in alternation, the rate of increase of stimulus amplitude from threshold to SMAX is adjusted on each repetition so that PMAX will be reached in 7 sec. If PMAX is not reached by then, or if it is reached prior to that time, the stimulus amplitude will gradually decrease, allowing the leg to return to resting position in another 7 sec. If PMAX was not reached, SMAX is increased in proportion to the error between PMAX and the final position. If PMAX was reached early, SMAX is replaced with the stimulus amplitude at the time PMAX was reached. The computer continually checks to determine whether special conditions (including operator commands) have occured indicating that stimulation should be discontinued. For example, if the stimulus current is at maximum and the leg fails to extend more than 20 degrees from rest, it is considered to be fatigued and stimulation of that leg is terminated. EKG, leg position, and stimulus voltages are recorded on a polygraph, while stimulus parameters, leg extension values, heart rate, and leg temperature are printed out with each repetition.

RESULTS

Several subjects have been tested on the LPV simulator. A partial record of one session showing stimulus amplitudes and leg extension values is shown in Fig. 3. The subject lifted 2 kg with

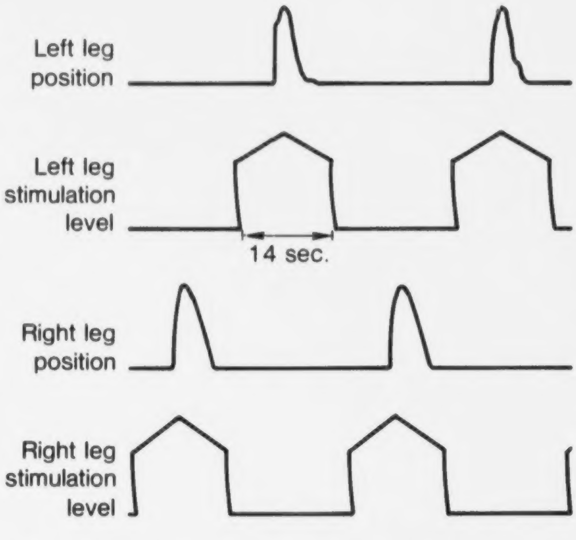

Fig. 3. Recordings of two extension-flexion cycles for the right and left legs.

the legs extending and flexing in alternation for approximately 6 sec each. Note that the stimulus initially jumps up to threshold and then gradually increases. Furthermore, leg movement does not occur until muscle tension exceeds the value of the weight. At that time, the leg extends in a nonlinear manner until either RMAX or SMAX is reached. Ipsilateral and contralateral reflex contraction of the knee extensors were observed in most subjects during initial trials which may be due to activation of the afferent fibers at stimulus levels just below threshold for activation of the efferent axons. In one subject with near normal sensation, such hyperactive reflexes were very pronounced. This phenomenon tended to diminish with repeated cycles of extension.

DISCUSSION

In order to avoid overstressing the legs, which might result in muscle, bone, or joint injury, a progressive intensity exercise protocol has been developed after preliminary testing of the LPV simulator. This protocol is used both to evaluate the fitness level of the paralyzed limbs and for further conditioning. The subject lifts a given weight (0.5 kg for the first session) during two sets of 20 consecutive repetitions. The sets are spaced 10 minutes apart. If the subject successfully completes both exercise sets without showing fatigue, the weight for that leg is increased by 0.5 kg for the next session. At this weight progression, it may take several sessions before fatigue is observed. The maximum weight which can be lifted throughout an exercise session, and which does not result in fatigue, may be used as an index of muscle fitness.

If the weight is great enough to cause the quadriceps to begin to fatigue, SMAX slowly increases, causing additional muscle fibers to be recruited which will maintain peak leg extension at PMAX. This period may be followed by a phase of more rapid fatigue during which SMAX increases rapidly and peak leg extension declines. It has been noted that the skin temperature above the quadriceps generally increases about 4-5°C in parallel with the increase in SMAX.

Exercise conditioning is accomplished by performing the above protocol at a weight level 0.5 kg above that which can be accomplished without fatigue. When fitness is improved to the point at which a session can be completed without fatigue, the weight level is again increased by 0.5 kg. This progression of increasing loads continues until the desired level of strength is achieved. At this point the duration of the exercise bouts may be increased to further increase endurance.

A number of benefits may be expected from electrically stimulating paralyzed muscles. These include increased muscle strength and endurance, increased bone strength, improved circulation, improved cardiopulmonary fitness, and especially the possibility of using the muscles for locomotion. However, such conditioning must be undertaken gradually so as to avoid overtaxing the atrophied muscles and osteoporotic bones.

ACKNOWLEDGMENT

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REFERENCES

1. Garcia, E.F., R.M. Glaser, B.M. Fichtenbaum, T.J. Ruchman and J.S. Petrofsky. Stress analysis for operating a multipropulsion mode wheelchair. Abst. #7.19, Physiologist 25:201 (1982).

2. Peckham, P.H., J.T. Mortimer and E.B. Marsolais. Alteration in the force and fatigability of skeletal muscle in quadriplegic humans following exercise induced by chronic electrical stimulation. Clin. Orthop. & Related Res. 114: 326-334 (1976).

3. Salmons, S. and G. Vrbova. The influence of activity on some contractile characteristics of mammalian fast and slow muscles. J.Physiol. 201:535-549 (1969).

4. Cooper, E.B., W.H. Bunch and J.F. Campa. Effects of chronic human neuromuscular stimulation. Surg. Forum. 24:477-479 (1973).

5. Kralj, A. and S. Grobelnik. Functional electrical stimulation: A new hope for paraplegic patients. Bull. of Prosth. Res. 10-20, Fall, 1973.

6. Mortimer, J.T. Motor Prostheses. Handbook of Physiology - The Nervous System II. J.M. Brookhart, V.B. Mountcastle, V.B. Brooks and S.R. Geiger (Eds.), pp. 155-187. Am. Physiol. Soc., Bethesda, MD, 1981.

7. Munsat, T.L., D. McNeal and R. Waters. Effects of nerve stimulation on human muscle. Arch. Neurol. 33:608-617 (1976).

8. Riley, D.A. and Allin, E.F. The effects of inactivity, programmed stimulation, and denervation on the histochemistry of skeletal muscle fiber types. Exp. Neurol. 40:391-413 (1973).

9. Glaser, R.M., J.S. Petrofsky, J.A. Gruner and B.A. Green. Isometric strength and endurance of electrically stimulate leg muscles of quadriplegics. Abst. #31.11, Physiologist 25:253 (1982).

10. Petrofsky, J.S., R.M. Glaser, C.A. Phillips and J.A. Gruner. The effect of electrically induced bicycle ergometer exercise on blood pressure and heart rate. Abst. #31.12, Physiologist 25:253 (1982).

Mailing Address: Dr. John A. Gruner,
Department of Physiology, Wright State
University School of Medicine, Dayton, Ohio 45435

3.11P

MULTISITE ELECTRICAL STIMULATION FOR THERAPEUTIC AND ORTHOTIC REHABILITATION OF PARETIC GAIT

M. Malezič, M. Kljajić, U. Stanič, R. Aćimović*, J. Krajnik*, N. Gros*,
M. Stopar

J. Stefan Institute, Ljubljana; *Rehabilitation Institute, Ljubljana, Yugoslavia

Since the invention of three-site stimulation for correction of hemiplegic gait (1), several further investigations established it as a meaningful rehabilitation tool.

Six-site surface electrical stimulation was introduced as a successful clinical therapy for correction of severely impaired gait (2). Yet as it is now, it is too demanding to be performed by the patient alone outside the clinic. Therefore, a research program of both therapeutic and orthotic use of the multisite functional electrical stimulation (MFES) has been carried out. Immediate effects of MFES, its long term effects, and an optimisation of number of stimulation sites for orthotic use are presented together with measuring and evaluation methods.

The immediate effects of MFES on 11 hemiplegic patients showed that the surface stimulation of main leg muscles during gait lessened or corrected most of the typical anomalies (2). The average correction was higher in the swing than in the stance. Significant corrections in stride time, stance time, and symetry of gait were also achieved. In the early phase of rehabilitation, MFES helped establishing antigravity support and initiating gait. Later on, MFES corrected abnormal gait pattern and enabled patients to walk longer.

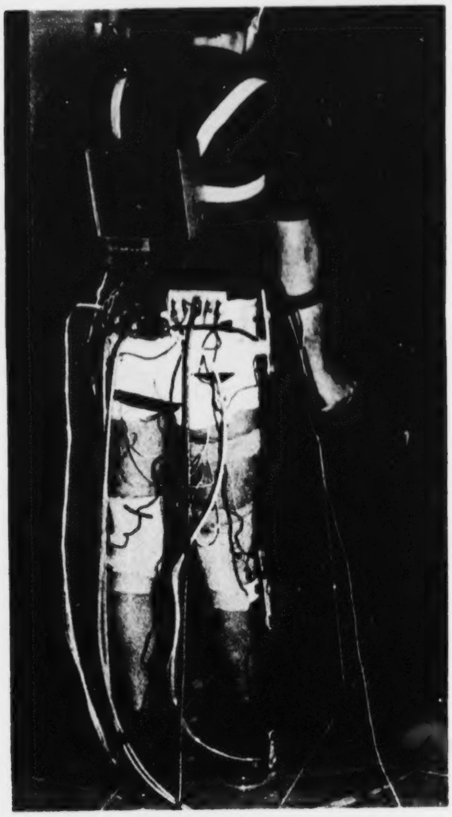


Fig. 1.

In Fig.1, a patient with the six-channel stimulator, surface electrodes, force shoes and crutches, and goniometers is presented. Qualitative and quantitative evaluation of gait included a kinesiological analysis, consisted of 55 observations of anomalies at leg joints, posture, and symetry during the swing phase, loading, stance, and push-off, rating them from 1 to 3 where observed (3). Besides, the average stride length and the velocity of gait were measured together with the ground reaction forces under shoes and crutches, the goniograms and EMG recordings (5). An extensive software package was developed for computer representation of data.

In a control study of long term effects of MFES (4,5) with 10 stimulated patients and 10 control patients, the therapy of every patient lasted 2 to 3.5 months. Similarity of both groups was achieved in: a status after insult, adequate motivation, period from the insult to the start of therapy (5 months), accompanying pathologies, and period of the therapy. The control group was formed from 5 left and 5 right hemiplegics, while the stimulated one included 4 left and 6 right hemiplegics. Both groups were treated daily for an equal amount of time. The control one was involved in a regular therapeutic program, the stimulated one was partly included in it and treated by MFES daily from 10 minutes to more than one hour from the start to the end of therapy. The stimulation time was being adapted to fittness of each patient individually.

Adequate MFES was applied to the stimulated patients according to their disabilities and MFES methodology (2,4). Sequences of stimulating channels during the stride were determined for each patient observing his motoric lacks. MFES was applied to pretibial muscles and plantar flexors of ankle, knee extensors and flexors, hip extensors and abductors, where in cases with sufficient hip abduction during stance, one of the channels was applied to elbow extensors for the reciprocal movement of arm in swing.

The kinesiological analysis of gait was accomplished at the start, at the end of therapy, and after 5 to 11 months without treatment. Better improvement of the anomalies was achieved at the stimulated group: 38% at the end of therapy when normalized with initial scores of ratings at the start, and 29% after longer period without treatment, compared with 21% at the end and 27% later at the control group. The scores also revealed higher starting point of the control group, where all the patients were able to walk independently at the start of therapy. The patients in stimulated group could all walk by themselves too at the end of therapy. However, the improvements of both groups sinked after longer period without treatment to approximatelly equal values: 29% for the stimulated and 27% for the control group.

Mean values of the average stride length L normalized to the initial values, increased considerably more at the stimulated group (29%) than at the control one (15%) at the end of therapy (Fig.2), both approaching similar values after longer period (18% and 16%).

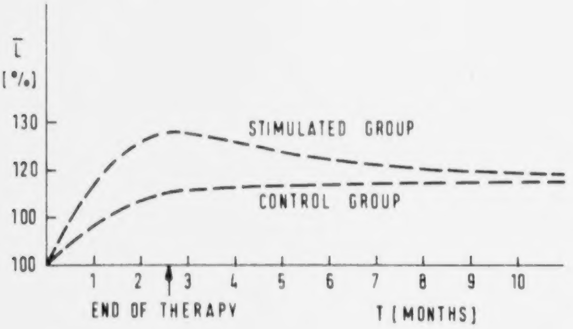


Fig. 2.

The average velocity of gait V reached similar values at the end of therapy for both groups (Fig.3) (41% stimulated and 48% control group). During the post-therapeutic period, V changed slightly at the stimulated (43%) and considerably at the control group (68%).

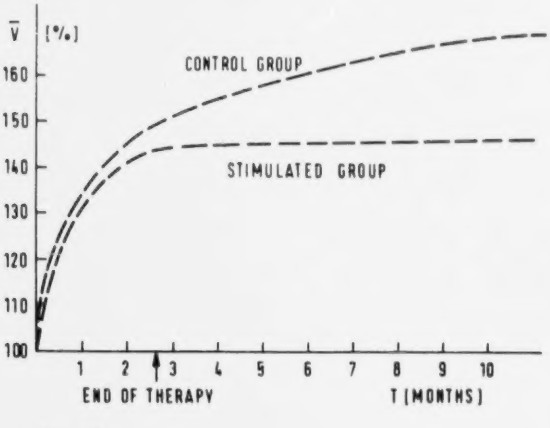


Fig. 3.

Considering the gradients of both parameters, the results of kinesiological analysis of gait, and the lower starting points of stimulated group, MFES rehabilitated patients better and faster than regular therapy. However, its therapeutic effects were slowly fading during long post-therapeutic period.

The measurements of ground reaction forces under both feet and crutches and goniograms of joint angles corresponded to these results, as well as EMG recordings before (Fig.4) and at the end of therapy (Fig.5) where larger activation, stronger contraction, better cyclic activity, reciprocal innervation, and coordination at the stimulated group also partly faded after longer period.

Observing the immediate effects of MFES at the end of therapy, larger improvements compared with the results of previous studies (2) implied also significant correction of the stance phase of gait due to MFES methodology (4).

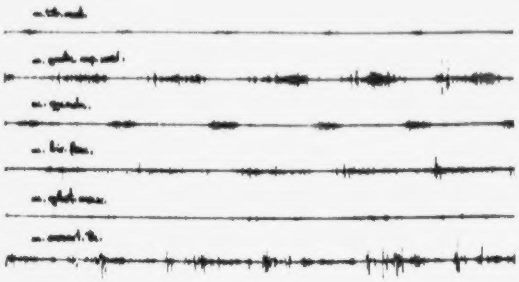
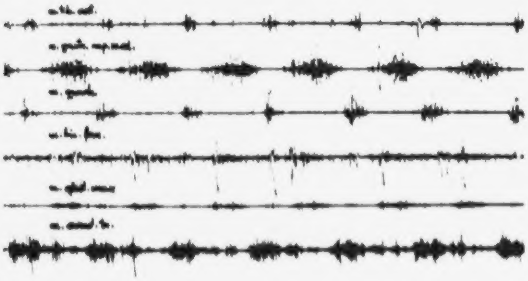


Fig. 4.

Fig. 5.



The results gave no final answer about existence of sufficient long term effects of MFES therapy, which would indicate only simple single-channel orthotic devices or even no stimulation necessary after the end of MFES therapy. The present six-channel stimulation has been too demanding outside the clinical environment. So, dual site orthotic stimulation has seemed a considerable functional extension of usual single site one and has been still acceptable for the patients in their normal environment (6).

Effects of single-, dual-, an six-site stimulation have been compared on 1 multiple sclerosis, 4 left, and 6 right side hemiplegic patients. The peroneal stimulation has been applied for single site, ankle dorsal and plantar flexors, knee extensors and flexors, hip and elbow extensors have been stimulated at six sites, while pretibial muscles and knee exten-

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sors have been chosen for the dual site stimulation. Optimal stimulation sequences have been determined for each patient individually in 3 to 5 sessions.

Table 1:

	without	1 st.	2 st.	6 st.
K.A.G.	39.4	29.6	25.9	21.7
L (m)	0.79	0.87	0.90	0.89
V (m/s)	0.11	0.49	0.51	0.51

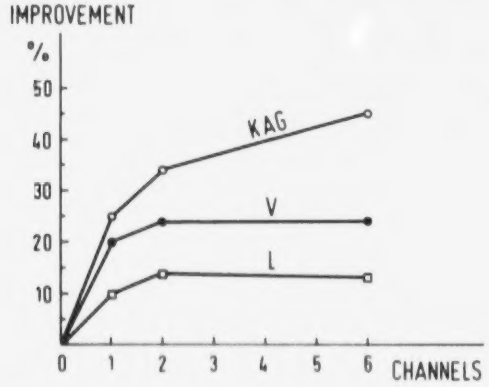

Fig. 6.

The kinesiological analysis with measurements of average stride length L and gait velocity V have been completed without and with the three different stimulations (Table 1: absolute mean values; Fig.6: normalized ones).

With the increasing number of stimulation sites, a considerable improvement has been recorded at kinesiological analysis, while improvements of the stride length and gait velocity have not increased over two sites of stimulation. The measurements of ground reaction forces and goniograms of joint angles have rendered corresponding results. Considering the present state of art at MFES with these results, the dual site stimulation seems optimal for the orthotic application outside clinical environment.

However, an overall experience favours MFES compared with other therapies as more intensive and efficient: with shorter rehabilitation periods, higher levels of improvement can be achieved. Though the present method of surface MFES suffers from several shortcommings (uselective and variable muscle responses, poor activation of deeper muscles, fatigue, time consuming positioning of electrodes, and lack of information about the status of whole control system), it is especially appropriate for severely handicapped patients, where it can reestablish or significantly improve the organization of motoric activity in gait.

Considering the decrease of therapeutic effects after longer periods, the orthotic application of MFES outside the clinic is strongly indicated. As the present surface MFES is too demanding for patients alone, the reduction of stimulation sites seems to be a useful partial solution for orthotic purposes.

The final solution: an autonomous implantable multisite stimulation of gait still entails several unsolved problems. Clinical evaluation of new peroneal pasive implant (7) with 17 patients implanted since April 1981, has solved few of them. The determination of stimulation sites, better control, new control signals, better adaptation, sources of energy still remain together with one of the greatest problems: our limited knowledge of natural control.

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REFERENCES

1. Kralj A.,Trnkoczy A.,Aćimović R., Improvement in locomotion in hemiplegic patients with multichannel electrical stimulation, Proc.Conf.Hum. Locomotor Eng.,Sussex,England,60-68,1971.
2. Stanič U.,Aćimović R.,Gros N.,Trnkoczy A., Bajd T.,Kljajić M., Multichannel electrical stimulation for correction of hemiplegic gait, Scand. J.Rehab.Med. 10,75-92,1978.
3. Stanič U.,Bajd T.,Valenčič V.,Kljajić M., Aćimović R., Standardization of kinematic gait measurements and automatic pathological pattern diagnostics, Scand.J.Rehab.Med. 9,95-105,1977.
4. Malezič M.,Krajnik J.,Stanič U.,Gros N., Aćimović R.,Pirnat P.,Stopar M.,Kljajić M., Long term effects of multichannel stimulation on pathological gait, Proc.7th Internat.Symp.External Control of Human Extremities,Dubrovnik, 409-419,1981.
5. Krajnik J.,Stanič U.,Malezič M.,Aćimović R., Gros N.,Kljajić M.,Pirnat P.,Stopar M., Experiences with multichannel electrical stimulation in the correction of hemiplegic gait, Proc.4th Conf.Rehab.Eng.,Washington,D.C.,238-243,1981.
6. Malezič M.,Krajnik J.,Stanič U.,Stopar M., Aćimović R.,Gros N., Optimisation of number of channels for electrical stimulation of pathological gait, Proc.World Congr.Med.Phys.,Biomed.Eng., Hamburg,12.32,1982.
7. Strojnik P.,Vavken E.,Aćimović R.,Stanič U., A new Ljubljana implantable peroneal stimulator, Proc.World Congr.Med.Phys.,Biomed.Eng., Hamburg,12.08,1982.

Matija Malezič, J. Stefan Institute, E. Kardelj University, Jamova 39, 61000 Ljubljana, Yugoslavia

VALIDATION OF SIMULATOR EVALUATION OF DISABLED DRIVERS

Dev S. Kochhar and Stefan Frembgen
The University of Michigan

Abstract

In an ongoing program, a part task driving simulator has been used for the training and evaluation of individuals with perceptual and psychomotor disabilities. Decisions made based on simulator evaluations need to be validated by a testing of driving performance on the road. As such, an instrumented automobile was used to evaluate the same individuals who had been previously evaluated on the simulator. This paper describes the method used.

INTRODUCTION

Residual capabilities that are necessary for the driving task can be evaluated in persons with perceptual disorders. Such evaluations can aid in the planning of training programs and in the determination of whether such individuals can be licensed to drive personal vehicles. More significantly, information gained from an evaluation of the residual capabilities can be useful to an appropriate redesign of vehicle dynamics and vehicle controls so as to assist the individual in the performance of the driving task.

In the past, several methods have been used to determine residual capabilities. A prominent method has been to use a part-task or full-task driving simulator to study several dimensions of driver behavior and driver performance, including driver-vehicle interactions, vehicle dynamics, study and validation of models of driver behavior, and examination of components of the driving task. In fact, a high proportion of current knowledge of driver behavior and performance is derived from experiments conducted on simulators which permit a study and isolation of the essential parameters of driving and driving skills. In earlier work, we reported on the use of a part-task, fixed base computer controlled driving simulator as a tool to identify those disabled persons who have the potential to be trained to drive (2). Further work was reported on the development of a general methodology, based on experimentation in a simulator, to identify persons who have the potential to become functional on-the-road drivers (3). In review, eight subjects with different perceptual dysfunctions were tested over a period of three months. It was observed from an analysis of time and frequency domain plots of steering control movements that some subjects improved significantly in the consistency of control over the test period. Also, these subjects indicated a positive learning trend, responded more quickly as the testing progressed and made fewer errors. (Fig. 1). For other subjects, no pattern of improvement could be detected. (Fig. 2). Thus, the simulator was used both as a screening as well as a training device (2,3).

As a next step, the results obtained from simulator studies are being transformed into a meaningful package that could be utilized by instructors for on-the-road training of perceptually disabled individuals. In this paper we report on the methodology developed and progress made in validating simulator results on the basis of on-the-road performance.

The validation of simulation based methods of identifying trainable and untrainable individuals on the basis of an evaluation of on-the-road performance requires the following tasks: (1) The development of criteria for identification of trainable individuals based upon on-the-road performance, (2) A comparative evaluation of identification procedures based on simulator and on-the-road studies, and (3) An identification of criteria for trainability and untrainability.

In establishing performance criteria, the objectives are to ensure that the criteria should reveal, in combination with medical diagnosis and simulator tests, whether a person with certain disabilities is trainable to become a safe driver and should therefore undergo the licensing procedure. It must be noted that this is, yet, an unusual approach to practical licensing; present methods used are most often without any scientific validation and based merely on subjective evaluation (4).

The necessary criteria should be based on measures of enabling objectives based on both objective and subjective parameters (1). Objective parameters are based on the two basic functions in driving, viz. speed control and steering action. The former includes accelerator pedal activation, brake pedal activation, longitudinal acceleration and the measurement of speed. The latter includes steering wheel angle and lateral acceleration. Subjective measures that rate driver behavior are based on the method reported by Jones (1) and used by Sivak et al. (5).

Performance criteria used for simulator based experimentation are primarily objective, although observations made by the experimenter help to provide interpretation of other non quantifiable phenomena. Objective parameters are based on speed control, steering action and on the quantitative assessment of spare mental capacity in the processing of information.

A comparative evaluation of the efficacy of the two procedures can be performed based on both subjective and objective measures.

METHOD

For on-the-road testing, a compact Dodge Omni was fitted with hand controls for accelerator and brake action. Dual controls enable an experienced driving instructor to take over control in an emergency. A compact accelerometer was mounted on the transmission for the recording of lateral and longitudinal acceleration. A force transducer was mounted to record the frequency and severity of braking action. Potentiometers were mounted to record steering control.

The driving course was essentially the same as that used by Sivak et al (5). This is an in-traffic driving course that comprised left and right turns, short and long driving stretches on both divided highway and downtown sections. Subjects actions such as gap acceptance, path following and the ability to read and follow posted speed limits are also noted.

All objective recordings are made on an 'on-board' A/D converter and HP-85 desktop computer. Data on steering action, gas pedal, and brake action and vehicle lateral and longitudinal acceleration are sampled at a rate of 12.9 samples/second. A rear wheel mounted revolutions counter provides information to the backseat mounted computer as to the progress of the automobile along the course.

SUBJECTS

The same eight subjects who participated in the earlier simulator based studies also participated in these tests.

TASKS AND RESULTS

The driving course is approximately one half hour in duration. Each subject was first given a trial session. This was followed on another day, by a data collection session. On subsequent, but not necessarily consecutive, days two more trial sessions were given, followed by a final data collection session. In designing the experiment, it was hypothesized that the final data collection session would reflect, to some degree, the learning effects of the sessions completed previously.

For each of the eleven segments that comprised the driving course, a record was kept of the rms lateral and longitudinal acceleration, the mean and absolute steering control deviations from a centerline, the average and maximum values of the linear travel of gas and brake pedals, and of all subjective observations made over the driving course.

All testing is in progress at the present time. We propose to discuss and present our findings in the oral presentation.

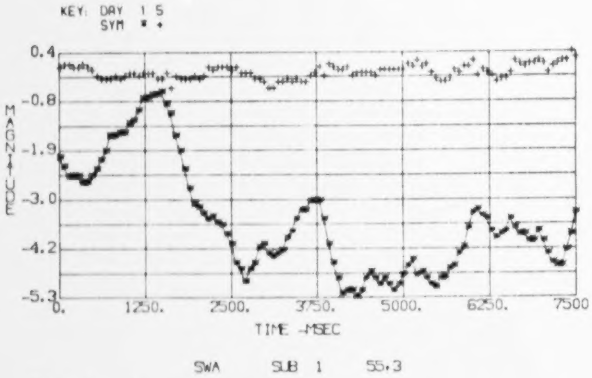

Fig. 1 (a): Time domain plot, steering control

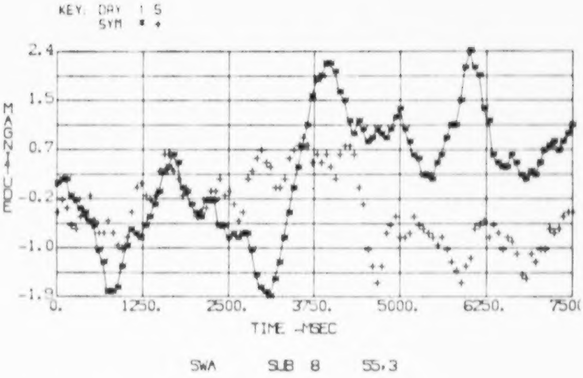

Fig. 2 (a): Time domain plot, steering control

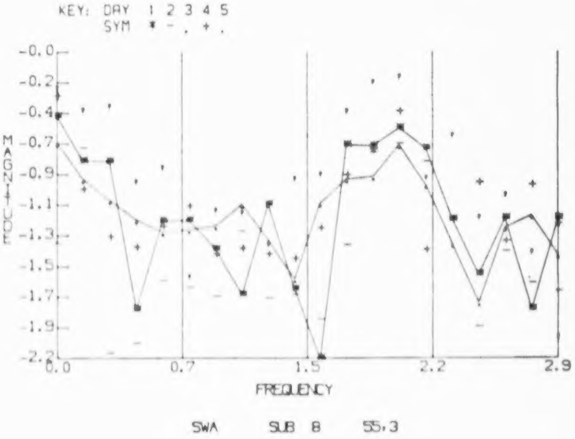

Fig. 2 (b): Frequency domain plot, steering control

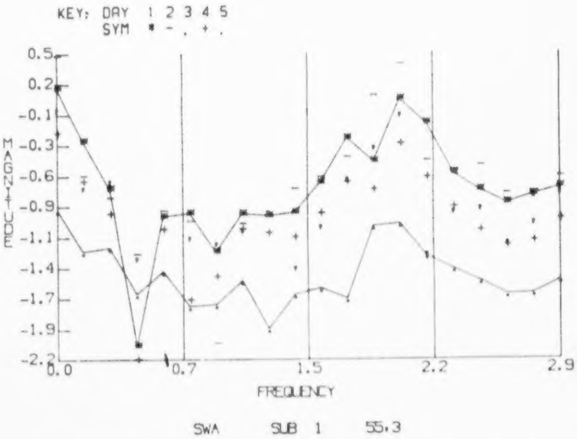

Fig. 1 (b): Frequency domain plot, steering control

ACKNOWLEDGEMENTS

Financial support was provided to the Rehabilitation Engineering Center of the University of Michigan by Grant No. G008200047 of the National Institute of Handicapped Research, Department of Education, Washington DC.

REFERENCES

1. Jones, M. H. 'Driver Performance Measures for the Safe Performance Curriculum.' Final Report, DOT Contract #DOT-HS-01263, Traffic Safety Center, Institute of Safety System Management, University of Southern California, LA, 1978

2. Kochhar, D.S., Miller, J. M., Boydstun, L. 'An approach to training the disabled driver.' Proceedings, IEEE International Conference on Cybernetics and Society. Atlanta, 1981, pp. 375-379.

3. Kochhar, D.S. "Disabled driver evaluation and training using an interactive simulator." Proceedings, 5th Annual Conference on Rehabilitation Engineering, Houston, 1982, p. 107

4. Lybrand, W. A., Carlson, H. H., Cleary, P. A., Bauer, B. H., "A Study on the Evaluation of Driver Education." Report # PB-180-471, DOT Contract # FH-11-6594, American University Development Education and Training Research Institute, Washington, D.C., 1968

5. Sivak, M., Hill, C. S., Olson, P. L., Henson, D. L., "Preliminary Testing of Techniques to Improve Driving Performance." Report # UM-HSRI-81-12 The University of Michigan, Highway Safety Research Institute, Ann Arbor, Michigan, 1981

ADDRESS

Rehabilitation Engineering Center, University
of Michigan, 2254 G. G. Brown Laboratory, Ann Arbor
Michigan 48109.

Driver Readiness Training for Persons with Brain Damage

Donald G. Kewman and Charles Seigerman
Rehabilitation Engineering Center
Department of Physical Medicine and Rehabilitation
University of Michigan

ABSTRACT

Persons after head injury often exhibit residual cognitive/perceptual deficits which affect safe operation of an automobile. A training program was developed utilizing a modified AMIGO electric wheelchair to simulate some actions of driving an automobile to teach brain injured persons driver readiness skills in a safe and controlled atmosphere. Skills trained included visual-motor tracking, perceptual-motor planning and divided attention. This training program is viewed as one component which can be added to standard training programs to teach brain injured persons safe driving skills.

INTRODUCTION

Head injury is a major cause of severe long term physical, cognitive and behavioral disability. A national survey reported approximately 422,000 persons per year suffer a head injury that results in at least a 24 hour stay in a hospital. Approximately 40,000 have a severe enough injury to require 20 or more days in the hospital. Interestingly, this compares with a national incidence of approximately 10,000 cases of spinal cord injury per year.[1]

People with brain injury often exhibit physical changes, cognitive/perceptual problems and behavioral difficulties as a result of the injury. The goal of rehabilitation is to help the brain injured become as independent as possible. Often a key to independence is access to appropriate transportation. The individually licensed automobile is sometimes the only practical means for a person to get to many educational, vocational or leisure activities.

Many persons with serious brain injury have difficulty benefitting from traditional driver training programs. Current driver training programs for the disabled often stress instruction in the use of highly specialized adaptive equipment. In the brain injured population it is usually not physical handicaps which prevent safe operation of an automobile. It is primarily cognitive/perceptual deficits which make driving difficult or impossible.

It has been reported that drivers with brain damage show decreased performance in observing or scanning road conditions and tracking or steering the vehicle. Also, problems are evident in spatial judgment and timing so that proper distance from other vehicles is maintained.

Bardach reported difficulties in hemiplegics (persons with lateralized brain lesions) such as left-right orientation problems, the inability to shift attentional set and high distractibility.[2] It has also been shown that driving performance of persons with brain damage is related to the extent of their cognitive/perceptual impairments.[3,4] It is recognized that attentional abilities are critical to driving especially the ability to divide attention so that multiple tasks can be processed simultaneously. People working with brain injured individuals often report that their patients have a difficult time attending to more than one task at a time.

A training program to teach cognitive and perceptual abilities involved in driving was developed and tested in order for this large segment of the disabled population to have an opportunity to learn to safely operate a motor vehicle. It was designed to precede a formal on-the-road handicapped driver training program.

METHODS

Subjects. Thirteen subjects were selected for training who met the following criteria:

1. minimum six months post severe closed head injury. Severity was defined by a minimum hospitalization of one month and impaired consciousness (coma) of at least 24 hours.
2. not currently driving
3. reached the minimum driving age in the State of Michigan of 15 1/2 years
4. a cognitive level where there is carry-over of new learning and operation of an automobile seems, at least, remotely possible.

Eleven non-brain injured high school students, who were currently licensed served as a control group for the attention exercise and the on-the-road driving evaluation.

EQUIPMENT

A standard electric AMIGO wheelchair (figure 1) was modified to simulate some actions of driving an automobile. The modifications included: 1) exchanging the standard "T" bar with a 12 inch steering wheel, 2) installing a foot operated accelerator and mechanical brake, 3) adding an electric horn, 4) adding dual seat posts so that the seat can be moved back to accomodate subjects regardless of height and 5) installing front stabilization pads to help prevent tip over. Several subjects required additional modification which included a left foot accelerator and a thumb control for acceleration.

Training trials were timed by an electric clock controlled by floor switches at the beginning and end of each training configuration or by a stop watch. For the visual monitoring tasks, signs were mechanically presented by a device designed specifically for the project. In the auditory monitoring task, a portable stereo tape player was used to present the auditory stimuli.

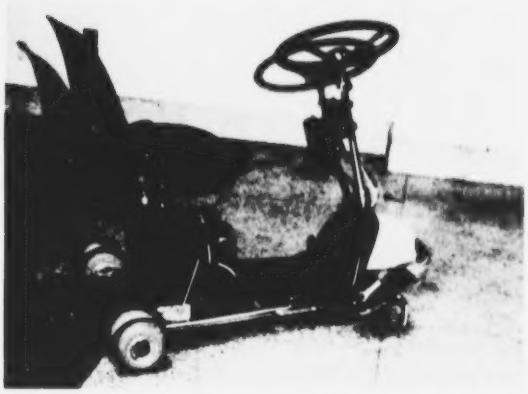

FIGURE 1. Modified AMIGO electric wheelchair.

PROCEDURE

The project was divided into three phases: pre-training evaluation, training and post-training re-evaluation.

Driving Evaluations. Each subject's automobile driving performance was evaluated on city streets by an experimenter who rates ability to maintain lane position, control speed, execute accurate turns and observe specific road signs. In addition, the experimenter counted the number of "fatal errors" which were defined as: 1) an unplanned maneuver where wheels hit the curb or shoulder, 2) an unplanned maneuver where the car intrudes into a lane of oncoming traffic, 3) going through stop signs or red traffic lights, 4) not yielding to vehicles or pedestrians so that a collision is possible and 5) any other braking or tracking error where there is an imminent danger of hitting or being hit. At the conclusion of each driving evaluation, an overall rating was assigned to each driver by an experienced driver educator for the disabled. The driving evaluation was repeated at the completion of training.

Cognitive/Perceptual Evaluation. Each subject was administered a brief cognitive/perceptual evaluation using psychological tests which have been previously identified as sensitive to driving ability.3 These tests were also repeated after the conclusion of the program.

Training Program. The training protocol developed for this experiment consisted of eight two hour driving sessions where subjects were trained on seven driving related tasks using the modified AMIGO wheelchair. All training was conducted at a local high school in a small multi-purpose room. The training tasks consisted of seven driving configurations: 1) straight-away, 2) S-curve, 3) figure-eight, 4) serpentine, 5) serpentine with special visual monitoring designed as a divided attention task, 6) serpentine with special auditory monitoring designed as a divided attention task and 7) serpentine with both the visual and auditory monitoring.

The visual monitoring task consisted of the automatic presentation of road signs on each side of the serpentine. The subject called out the sign as he simultaneously negotiated the serpentine. In the auditory monitoring task the subject listened to a tape recording of randomly presented numerals interspersed with words. The subject responded whenever he heard a word as opposed to a numeral while simultaneously negotiating the serpentine. In the combined visual and auditory monitoring task, the subject simultaneuosly negotiated the serpentine, called out the signs and responded to the audiotape of numerals and words.

Aluminum soft drink cans were used to outline the course configuration for each task. Several trials were given for each task. Feedback on performance and encouragement was given. The task was then made more difficult by moving the cans closer together. In all tasks data was collected on the time taken to complete each trial and the number of can hit. For the divided attention tasks, data on the accuracy of the monitoring was also collected.

RESULTS

Subjects showed substantial improvement in all AMIGO training tasks. Preliminary results of the driver education teacher's rating of each subjects operation of an automobile in traffic indicate that nine of the thirteen brain injured subjects showed improvement of at least one rating point (on a five point scale) with two improving one half scale point and two remaining the same. In addition, three participants improved sufficiently to be recommended for a license. A more detailed analysis will be presented at the conference.

DISCUSSION

Results of this project suggest that training using a vehicle that simulates some features of automobile driving prior to formal on-the-road driver training could assist a large segment of the cognitively/perceptually disabled population to learn to safely operate an automobile. This program and others being tested at the University of Michigan Rehabilitation Enginnering Center represent initial efforts to develop components of a comprehensive training program to train persons with cognitive/perceptual deficits to drive. By testing alternative instructional systems it is hoped that skills which are deficient can be remediated safely and efficiently. Future research is needed in both driver training and other areas where cognitive/perceptual deficits continue to limit independence.

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REFERENCES

1. Kalsbeek, W.D., McLaurin, R.L., Harris, B., Miller, D.J. The national head and spinal cord injury survey major findings. Journal of Neurosurgery, 1980, 53, 519-531.
2. Bardach, J.L. Psychological factors in the handicapped driver. Archives of Physical Medicine and Rehabilitation, 1971, 52, 328-332.
3. Sivak, M., Olson, P.L., Kewman, D.G., Won, H., and Henson, D.H. Driving and perceptual/cognitive skills: Behavioral consequences of brain damage. Archives of Physical Medicine and Rehabilitation, 1981, 62, 476-483.
4. Strano, C.M., Idiculla, A.A., and Glass, D.D. Study of relationships between visual/perceptual skills and the ability to drive in the adult with brain injury. Paper presented at the 59th Annual Session of the American Congress of Rehabilitation Medicine, Houston, November, 1982.

Authors address:

Donald G. Kewman, Ph.D.
University Hospital
Department of Physical Medicine and
Rehabilitation
1405 E. Ann Street
Ann Arbor, MI 48109

IMPROVED DRIVING PERFORMANCE FOLLOWING PERCEPTUAL TRAINING OF PERSONS WITH BRAIN DAMAGE

Michael Sivak, Carole S. Hill, Donald L. Henson
Barclay P. Butler, Sharon M. Silber, and Paul L. Olson
Rehabilitation Engineering Center
The University of Michigan Transportation Research Institute

INTRODUCTION

Brain damage often results not only in physical impairment but in perceptual deficits as well. Sivak et al. (1) have shown that driving performance of persons with brain damage is directly related to the extent of their perceptual impairment. Specifically, persons with brain damage who scored well on certain perceptual tests tended to show good driving performance as well. Furthermore, the results implied that the driving-related problems encountered by some of the persons with brain damage were due primarily to impaired perceptual skills. These findings suggest that therapeutic techniques capable of improving the impaired perceptual skills might improve driving performance as well. This hypothesis was tested in the present study.

METHOD

Overall Design of the Study

The sequence of activities for the subjects was as follows:

(a) Pre-training evaluation of perceptual skills.
(b) Pre-training evaluation of in-traffic driving performance.
(c) Perceptual training.
(d) Post-training evaluation of perceptual skills.
(e) Post-training evaluation of in-traffic driving performance.

Subjects

Eight subjects participated in the study. The criteria for selection of subjects were: (a) a history of acquired (as opposed to congenital) brain damage, (b) substantial perceptual deficits, (c) pre-injury driving experience, and (d) marked difficulty in relearning to drive.

Perceptual Evaluation

Standard perceptual tests were used to evaluate pre- and post-training perceptual capabilities.

Driving Evaluation

Driving performance was evaluated on a specially designed and validated in-traffic driving course (1). Each subject's in-traffic driving was tested on the same 10-mile course, by scoring the execution of 166 predetermined test actions. Each subject was given repeated evaluations of driving performance prior to training, in order to stabilize the driving performance before commencing perceptual training.

Perceptual Training

Subjects received a total of 8 to 10 hours of individualized training, distributed over 5 to 9 sessions. The training, consisting of paper-and-pencil exercises, was designed to require use of a wide range of perceptual and cognitive skills and abilities. These included visual scanning, directed eye movements, spatial perception and discrimination, figure/ground differentiation, visual imagery, attentional capacity, and general problem-solving approach.

RESULTS

The results indicate that (1) perceptual skills improved following the perceptual training, (b) the training was associated with improved driving performance, and (c) the degree of driving-performance improvement was directly related to the degree of perceptual improvement.

DISCUSSION

The present findings are very promising. However, validations with larger samples are necessary to firmly establish the benefits of perceptual training. Furthermore, several important issues have not been addressed yet and will have to be eventually researched. These issues include the optimal time course, format, and content of perceptual training, and how these parameters might vary with etiology.

Finally, if driving is improved following perceptual training, it is likely that a range of other activities of daily living (where perceptual skills are often essential) may benefit as well. Therefore, perceptual training to improve driving performance may indeed constitute perceptual training to improve driving, walking, general navigation, as well as home and work activities. The potentially broad implications of perceptual training remain to be ascertained.

REFERENCE

1. Sivak, M., Olson, P.L., Kewman, D.G., Won, H., and Henson, D.H. Driving and perceptual/cognitive skills: behavioral consequences of brain damage. Archives of Physical Medicine and Rehabilitation, 1981, 62, 476-483.

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ADDRESS

Dr. Michael Sivak, The University of Michigan Transportation Research Institute, 2901 Baxter Road, Ann Arbor, Michigan, 48109.

MODIFIED STEERING SYSTEMS FOR THE SEVERELY DISABLED DRIVER

M. Y. Zarrugh, R. Koopman and A. Haraldsdottir
Rehabilitation Engineering Center and
the Department of Mechanical Engineering and Applied Mechanics
University of Michigan, Ann Arbor MI 48109

ABSTRACT

In adapting conventional steering systems to the needs of drivers with severe physical limitations, the required effort and range of limb motion must be both reduced. Reduction of the range of limb motion increases the overall gain of the steering system which reduces the margin of stability of the system. Interactions between the driver and vehicle acting as a closed loop control system are studied using McRuer's "Cross-over" model. In particular, the effects of different driver parameters on maintaining stability at high speeds (80 km/hr) are investigated. Results show that increased driver time delay which characterizes persons with disability and increased steering gain which is a must for severely disabled drivers are detrimental to stability. The results also indicate the steering gear ratio must be variable with speed for stable regulation at all speeds.

INTRODUCTION

Conventional power-assisted steering systems are adapted to the capabilities of drivers with severe disability, such as those with injuries at high levels of the spinal cord, by reducing the range of steering wheel rotation and effort required for turning or parking. The first requirement can be satisfied by reducing the steering gear ratio, the second, by lowering the stiffness of the torsion bar (Fig. 1) of the steering gear which provides much of the resistance felt when the steering wheel is turned. This is usually accomplished by reducing the diameter of the original torsion bar. For example, in Ford Van Conversions the torsion bar is usually reduced from 0.195 to 0.125 inches which reduces the stiffness by a factor of six (Fig. 1). "Zero-effort steering" conversion in which the torsion bar is removed altogether is not common since this eliminates the automatic returnability of the steering wheel upon release.

The second modification of the steering system enables severely disabled drivers to use only small upper limb movements to turn or park. Most present adaptations do not satisfy this requirement because relatively fewer persons need such an adaptation and because this requirement necessitates the reduction of the steering gear ratio which has profound effects on the stability, especially at high speeds. Only one system, the Scott van (1) addresses both needs. After many design modifications, the steering system of the Scott van still revealed some undesirable features in a recent evaluation for the VA (2). Typical steering ratios are near 20:1 which means that a 20-degree steering wheel angle produces a 1° change in the direction of the front wheels. The Scott van has a gear ratio of about 5:1 which remains constant at all speeds. This, according to the evaluation (2), produces at high speeds unnecessary sensitivity that taxes the driver's attention and contributes to his fatigue. This is confirmed by results of driving tests conducted with able-bodied drivers to determine their preferences among several steering gear ratio schedules (3). Subjects preferred the gear ratio that varied from 16.5:1 to 7:1 and disliked the fixed 5:1 ratio the most (3).

This is the main motivation for conducting this study to assess the effects of changes of the gear ratio and other parameters on the stability of steering. This ultimately would lead to prescribing gear ratios that are suitable for stable operation at all speeds under the control of drivers with different degrees of disability.

BACKGROUND AND MODEL

Preliminary published data (1) indicates that there is a wide variation of driver characteristics due to disability and that steering behavior in the presence of adaptive equipment will also be varied and sometimes even superior (4). One of the principal driver characteristics that influences steering is the time delay or lag inherent in any neuromuscular activity. At high speeds, this delay should be as small as possible for a highly stable vehicle regulation (5). Literature indicate that a driver with disability has a larger time delay than able-bodied drivers when performing the same task on a driving simulator.

Two approaches have been adopted to determine the effects of varying the steering ratio (and hence the driver gain) and the driver time delay on the dynamics of steering. The first involves analytical models of the driver and the vehicle and the second, road tests measurements. Only the first approach is discussed here since analysis of our test data is not complete at this time. Vehicle dynamics are well understood. There is a concensus that for steering tasks,a simplified model is sufficient for representing the vehicle by its two dominant motions: lateral lane position and heading angle (5). Only relatively recently driver characterization became of interest. One important development is McRuer's "Cross-over" control law which relates driver parameters to those of the vehicle in simple terms. The law is based on pivotal quantity, the cross-over frequency, which is a measure of the range of frequencies over which system can follow input commands or suppress undesirable disturbances. McRuer et al. (7) state that drivers adjust their own dynamic parameters to achieve a particular frequency range of effective regulation regardless of the difficulties involved.

Dynamic driver behavior is characterized by four parameters (7). The first is the time constant T_L of the lead component by which the driver compensates for the vehicle's lag or its tendency not to respond instantly to steering inputs. High frequency driver dynamics are represented by time delay τ which in part accounts for neuromuscular transmission delay. The last two parameters are gains K_y and K_ψ which characterize the driver's sensitivity to lane position y and heading angle ψ respectively. A fifth parameter, the gear ratio GR couples driver actions to the dynamics of the vehicle and thus strongly influences effectiveness of driver control.

RESULTS AND DISCUSSION

The cross-over model is used as the bases for studying effects of the driver parameter and the steering gear ratio on stability at one high speed of 80 km/hr. The parameter of a 1969 Ford van were used in the vehicle model because the majority of handicapped persons drive vans. These parameters of the vehicle and speed were not varied during the simulation. The best estimate of the gain K_y is 0.5 rad/s for able-bodied drivers at 80 km/hr. This coefficient appears to be nearly independent of speed and thus remains relatively constant at a given speed (5, 7). In our study K_y was not altered. The driver lead time constant T_L appears to have little effect on stability when varied by ±20% from its estimated value of 0.158 s. Stability here means the response of the vehicle (i.e., y and ψ) does not increase indefinitely with time.

All of the rest of the driver-related parameter K_ψ, τ and GR do have a strong influence on the dynamics of steering when varied while keeping the speed and other vehicle parameters constant. The heading gain K_ψ was varied by ±20% from the approximate able-bodied driver value of 1.04 rad/s. Our results (Fig. 2) indicate that K_ψ strongly influences the stability of steering and the system becomes unstable when K_ψ is increased to 1.25 from 0.867 rad/s.

Another driver parameter which was varied is the gear ratio GR. This is very important for this study since the ultimate goal is to reduce the range of steering wheel motion by lowering the gear ratio so that the vehicle can be effectively controlled by the disabled driver. Four values of GR (21.5, 10, 6 and 2) were used. The typical steering ratio in vans is 21.5. Here K_ψ was kept constant at 1.04, T_L at 0.142 s and the driver time delay τ at 0.2 s. Figure 3 shows that vehicle lane position responses for GR of 6 and 2 are stable which is contrary to available evidence indicating that steering will become unstable at this speed and at such low gear ratios. More investigation is needed to explain why the model gives such prediction and modify it so that it produces acceptable predictions.

Recently more automobiles offer "variable ratio" steering systems in which the steering ratio is relatively high (say 18:1) when the steering wheel is in neutral position. This ratio drops quickly to a minimum value (typically 11:1) and stays at that level as the steering wheel is rotated about 1/4 turn away from the neutral position. This provides "quick" steering action during parking or cornering which normally occur at relatively low speeds. This variable ratio feature is desirable for severely disabled drivers but the range of ratio variation must be widened by lowering the minimum ratio so that stable regulation never needs steering action that is beyond the driver's capability. Thus, it is necessary first to assess the degree of functional limitation and accordingly prescribe suitable steering ratio range.

The last parameter to be studied is the effective time delay τ which is expected to be larger for drivers with disability. Early work indicates that τ ranges from 0.2 to 0.25 s (5,6). We varied τ from 0.15 to 0.25(Fig. 4) for several constant values of K_ψ. The results (Fig. 4) indicate that response and instability occurs at larger values of τ as K_ψ decreases.

CONCLUSIONS

These results should be considered as preliminary indications of how stability is influenced when driver parameters are altered. Conclusive statements can only be made after experimental data become available. It appears that the most important driver parameters affecting the stability of steering are the effective time delay and the gear ratio and that the time delay and heading angle gain are not independent. More analytical investigations are planned to determine the modifications necessary for stable steering by severely handicapped drivers. This will involve specifying a gear ratio schedule that varies not only with steering wheel position but also with vehicle speed.

ACKNOWLEDGEMENTS

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REFERENCES

1. Hogan, H. A. and Szeto, A. A simulation objective evaluations of physically handicapped drivers. IEEE - 1981 Frontiers of Engineering in Health Care, pp. 313-317, 1981.

2. McDermott, M. and Koppa, R. J. Summary test report of MED van's adaptive controls - Mark VI. Texas A&M University, March 1980.

3. Shoemaker, N. and Dell'Amico, F. A pilot experiment on driver task performance with fixed and variable steering ratio. Cornell Aeronautical Laboratory, Buffalo, New York, Report No. VK-2185-V-1, Sept. 1966.

4. Anger, R. T. and Mayne, R. W. The performance of automotive hand controls. American Society of Mechanical Engineers, Paper No. 76-WA/DSC-38, Dec. 1978.

5. Weir, D. H. and McRuer, D. T. Measurement and interpretation of driver steering behavior and performance. Human Factors 15:367-378, 1973.

6. Kochhar, D. S., Miller, J. M. and Boydstun, L. E. An approach to training the disabled driver. Proceedings, International Conference IEEE-SMC, Atlanta, Oct. 1981, pp. 375-379.

7. McRuer, D. T., Allen, R. W., Weir, D. H. and Klein, R. H. New results in driver steering control models. Human Factors 19:381-397, 1977.

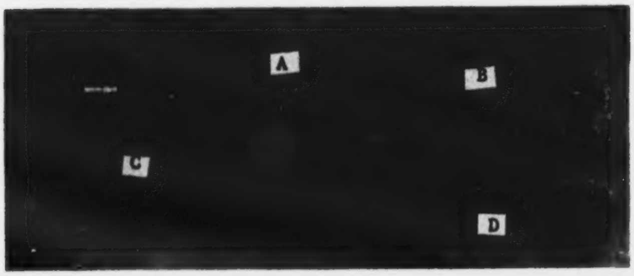


Fig. 1 **Input subassembly in power steering gear showing input shaft (A), modified torsion bar (B), and rotary control Valve (C). Unmodified torsion bar (D) is included for comparison.**

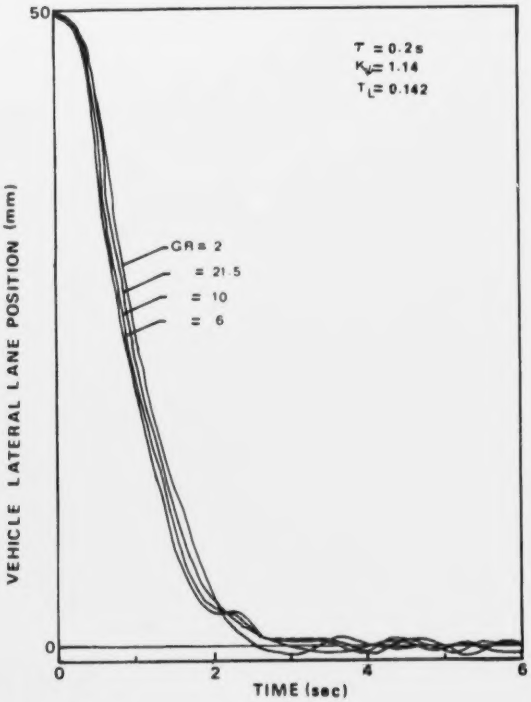


Fig. 3 Effects of varying the steering gear ratio on the control of vehicle lane position

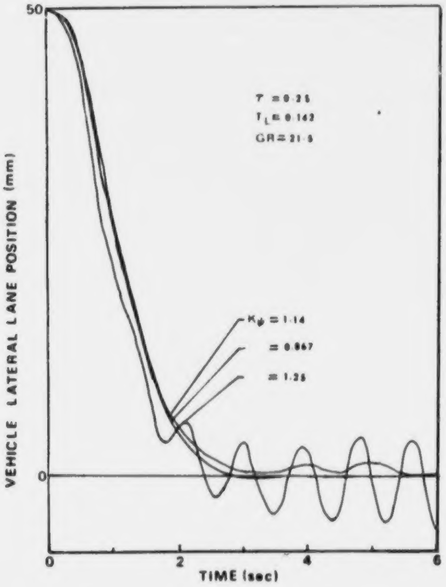


Fig. 2 Vehicle lane position response for several values of driver heading gain Kψ

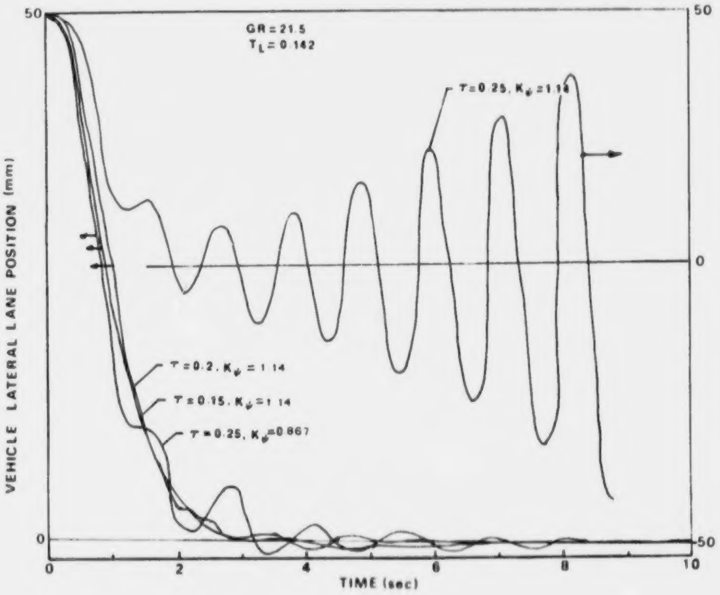


Fig. 4 Effects of driver time delay τ on steering at driver heading gain Kψ = 1.04 and 0.867

Department of Mechanical Engineering & Applied Mechanics
University of Michigan
225 West Engineering Building
Ann Arbor MI 48109

A TESTBED FOR VEHICULAR CONTROL SYSTEMS

Jon Z. Scott, Dr. Make McDermott, Jr., and Dr. Benjamin W. Mooring
Mechanical Engineering Department
Texas A&M University

INTRODUCTION

A need currently exists for technology that will allow severely handicapped persons to drive. Studies have shown that the mobility provided by personal transportation can be a very positive factor in the rehabilitation process. Under recent contracts from the Veterans Administration, the Rehabilitation Engineering Program at Texas A&M University studied the relative merits of several van modifications. These modifications ranged from low effort steering wheel and mechanical hand controls for driver input to servo systems which used various types of joysticks, levers, and wheels. These studies showed that the technology exists to construct very low effort steering and braking systems which can quickly and accurately position the wheels or apply the brakes in response to a driver input. However, despite excellent control hardware most high gain (low range of motion) systems could not be safely driven at highway speeds.

Not enough is known about the driver/vehicle interactions to design a high gain control system which is driveable at all speeds encountered in normal driving. Two major factors which influence the design of such a system became obvious. One factor is that vehicle lateral acceleration response to a steering input is proportional to speed squared. As vehicle steering gain increases with speed, the driver must decrease his internal gain in order to maintain control. For systems with high static gain this imposes a very high work load on the driver at highway speeds. Systems which incorporated control logic to reduce gain with increased speed were more driveable than fixed gain systems. The second factor is the reduction or loss of motion and force feedbacks to the driver with high gain systems. The effects of these factors were masked by the effects of other variables when testing different controls with a variety of vehicles and drivers.

In order to minimize the number of variables when comparing different controls a decision was made to construct a test vehicle for study of the driver/vehicle interaction. The vehicle was designed to allow quick and easy modifications to both the driver interfaces and the vehicle control strategy. This allows quick changes to be made and their effects documented. For this reason, a microprocessor based steering and brake control was designed and constructed. The steering and braking inputs from the driver are fed into the computer and the vehicle response is controlled by the computer. In this way, both the driver interface and the vehicle control strategy may be altered in a matter of minutes.

This paper describes the design and construction of the testbed system. Unfortunately, the program funding was terminated just after the vehicle was completed so the van has not been used for data collection as intended. We present this work in hope that it will assist other researchers in related studies.

SYSTEM HARDWARE

A 1975 Chevrolet van was available which had already been outfitted with an electro/hydraulic joystick system from Sevier Manufacturing Company. The van's hardwired electronics were bypassed with a microcomputer in such a way that either electronics or computer could be used to process control signals. The steering, accelerator and brakes were all hydraulically powered and controlled by electro/hydraulic pilot valves.

Fig. 1 shows the driver's area. Notice that no steering wheel or pedals are present, only a joystick mounted on the box in the driver's seat. The shifter mounted on the floor to the driver's rignt controls the automatic transmission. A kill switch, located on the dash just to the right of the gauges, shuts down the engine and applies the brakes for a rapid but smooth stop. This switch is available to the driver as a last resort measure only.

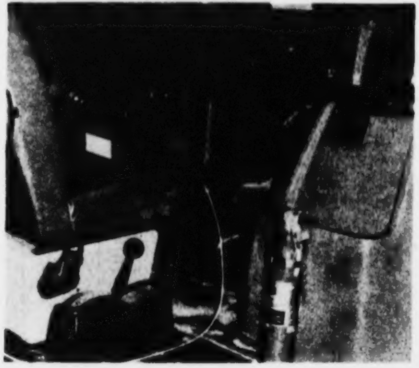


Fig. 1 Driver's Area

Figure 2 shows the workbench housing the computer and a seat for the system operator. From here, the control algorithm can be modified quickly by changing a Fortran program. The switch box selecting computer or hardwired electronics is also on the workbench.

PARAMETER IDENTIFICATION

Frequency response was the method used to identify the transfer function of the steering system's hydraulic and mechanical hardware. A sinusoidal input was applied to the steering pilot valve. A potentiometer on the steering gear was used to find the resulting motion on the front wheels.

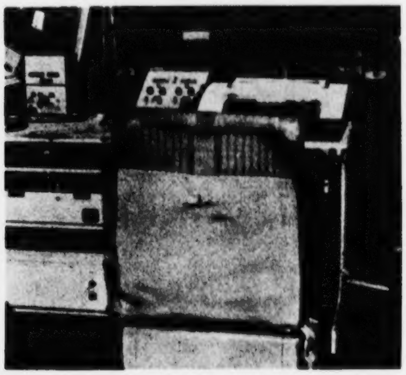


Fig. 2 Workbench

Fig. 3 shows a plot of frequency response data and a curve fit for an engine speed of 2800-3000 RPM. The transfer function

$$\frac{VO}{VI} = \frac{0.562}{s(1+s/5)} \qquad (1)$$

was used to curve fit the data. Higher engine speeds gave quicker response than lower speeds up to 1200 RPM. However, steering response was independent of engine speed over 1200 RPM. Therefore, the function producing the curve shown in Fig. 3 models the steering hardware for any speed from a fast idle (1200 RPM) through highway speeds.

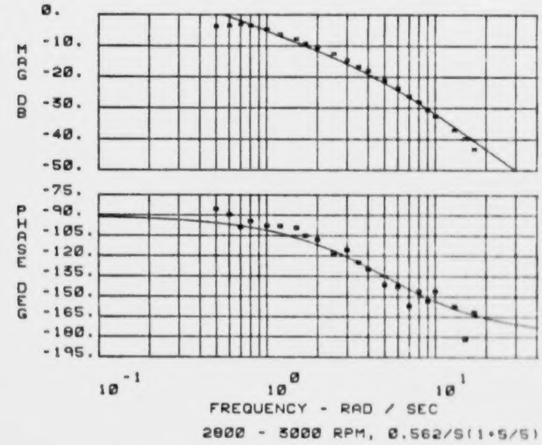


Fig. 3 Frequency Response Data

CONTROLLER DESIGN

Tests were run using controllers having only proportional feedback. These tests revealed that high controller gains were necessary to get rapid response of the front wheels to a joystick signal. However, high gains also produced unacceptable overshoot. The classical way around this problem is to add velocity feedback, which introduces artificial damping and allows much higher gains to improve response time with little overshoot.

Due to funding restrictions, it was decided to implement the velocity feedback with software. Two methods were considered: implementing velocity feedback by differentiating the steering potentiometer signal or using proportional plus derivative control by differentiating the error signal. Ogata [1] discusses the relative merits of each method. Proportional plus derivative control provides quicker response to step and ramp inputs and less steady state error to a ramp input. Velocity feedback has slightly less overshoot to a step input. Proportional plus derivative control was chosen on the basis of response time. For the resulting second order system, it was hoped that a damping ratio ζ could be chosen large enough to keep overshoot small while giving acceptable tracking and error performance.

Fig. 4 shows the block diagram for the proportional plus derivative controller. It was found that the van's electro/hydraulic hardware did not respond to control inputs within +/-0.5V. This dead-zone nonlinearity was removed with software. Both the dead-zone and the software to remove it have been lumped together into the nonlinear block N in Fig. 4. Notice that two constants are available for adjustment: K, the proportional sensitivity and T, the derivative time.

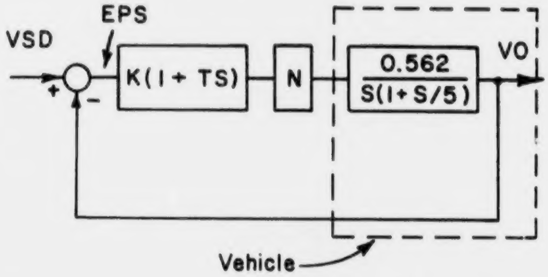


Fig. 4 Proportional Plus Derivative Controller

Differentiation of the error signal was implemented by calculating its slope at three successive time periods and using the average as the value of the derivative. This was done to remove the large errors that noise could cause in the slope. It was found that using more than three time periods caused excessive overshoot in the response. This is probably because each time period was about 0.03 seconds long and using three time periods meant using information that was 0.09 seconds old. As more time periods were used, the controller's information became more outdated. Therefore, the controller would not realize that the desired state was reached until several time periods after it had already happened. At the correct state, the controller believes it is still in error and continues moving the front wheels past the desired position and overshoots. Apparently, three periods was a good trade-off between noise effects and overshoot.

The characteristic equation of this closed loop system is:

$$s^2 + (5 + 2.81KT)s + 2.81K=0 \qquad (2)$$

A useful relation among T, K and Z can be derived as:

$$T = \frac{Z\sqrt{2.81K} - 2.5}{1.405K} \qquad (3)$$

The root loci for this system are shown in Fig. 5. Choosing K and T such that the roots of the characteristic equation are near the breakin point of Fig. 5 gives optimum response. At this point, the roots are at their left-most point, indicating the transient response will die out more rapidly here than at any other point.

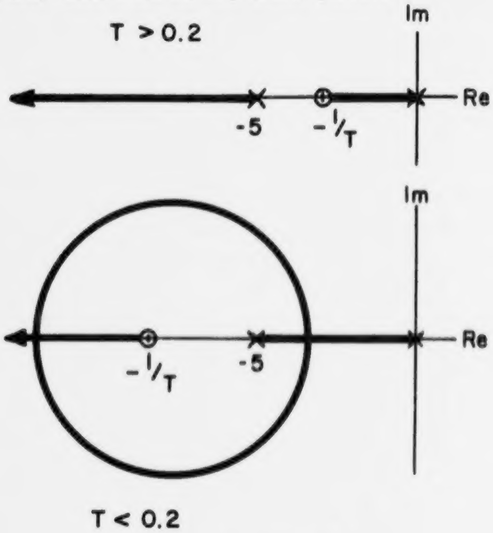


Fig. 5 Root loci

The root loci and equation (3) were combined into the more practical design chart shown in Fig. 6. Notice that for each value of T, two values of K exist for a given Z. The smaller values of K correspond to the sections of the root loci near the breakout point while the larger values of K correspond to the sections of the root loci near the breakin point, which is near the desired operating point. The dotted line in Fig. 6 intersects each curve at its maximum and the desired operating point is to the right of this curve.

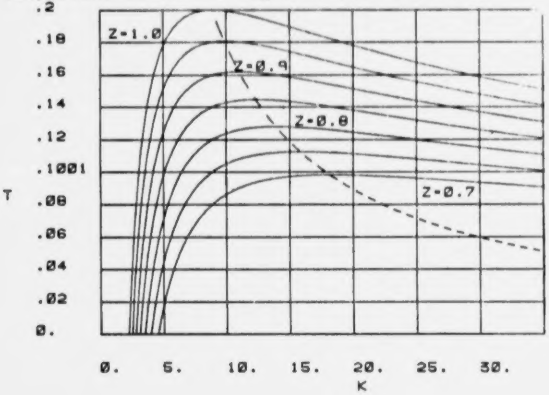


Fig. 6 Design Chart

Fig. 7 shows the best response obtained with this controller, using K=20.00 and T=0.1245 for a ζ of 0.80. The response of this controller appeared to be good enough to use as a starting point for experiments with test drivers.

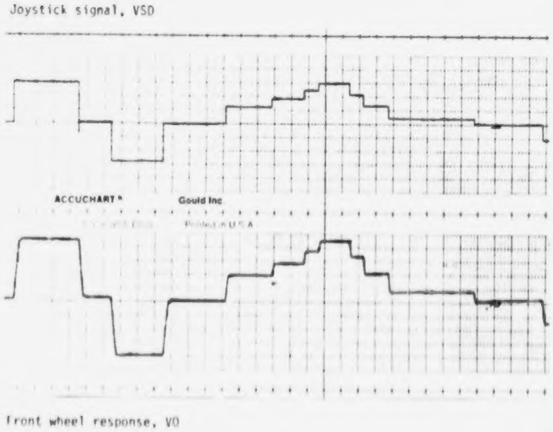


Fig. 7 Controller Response

FUTURE WORK

Many test drivers of joystick controllers report that a system driveable at 5 MPH is hard to control at 60 MPH. The vehicle lateral acceleration response increases with the square of speed so that evan a small change in front wheel angle at highway speeds causes a large lateral acceleration. One solution to this problem is to make steering gain a function of vehicle speed. This method could easily be implemented with the computer and some optimum relationship between gain and speed determined experimentally. Control devices other than a joystick could easily be connected and tests done to find a better method of vehicle control. These are the kinds of tests for which this testbed is ideally suited.

SUMMARY

A van containing an electro/hydraulic joystick system was modified for use as a testbed. A microcomputer was installed to process all the control signals. Frequency response tests were performed to find a transfer function fot the hydraulic and mechanical hardware. Frequency response data was plotted on a Bode diagram and a transfer function was fitted to the data. The root locus method was used to design two controllers: proportional and proportional plus derivative. The proportional controller exhibited sluggish response and a large steady state error. The proportional plus derivative controller's response was good enough to be considered for trials with test drivers. It exhibited good tracking of a joystick signal with little steady state error. The hydraulic hardware contained a dead-zone and this nonlinearity was removed in the computer software. Finally, some ideas for future work with this equipment were proposed.

REFERENCES

1. Ogata, Katsuhiko, Modern Control Engineering, Prentice Hall, Inc., Englewood Cliffs, NJ, pp. 341-344.

Jon Scott, M.E. Dept., Texas A&M University,
College Station, TX 77843

5.1 SELECTION OF BATTERY CHARGING SYSTEMS

Steve Brodsky, Project Engineer
Everest & Jennings Inc.

Batteries as a rule have not played an important role in the evolution of electronic controllers for the wheelchair or other electric powered vehicles for the disabled. Extended research time would be spent developing controllers and drive assemblies but when it came time for the power source, the process changed from a highly tuned matched status to an off-the-shelf purchased part.

The assumption was to simply bring the battery voltage up to some usable level by simply connecting the battery up to some voltage slightly higher than the intended finish charge voltage, observe polarities and the battery will be charged after some period of time.

This level of methodology fails to accomplish the completed evaluation of a charging cycle by neglecting the necessary coupling between the battery and its charging system.

A presentation of applicable criteria in coherent details of the variables discovered during usage and in the testing laboratories must be sufficient to insure a uniform coupling between the design and the application for its intended usage.

With the pipelining of new technical advancements, the alacrity to satisfy the demands of the market may tend to neutralize the need of system matching to a ridiculous state of over-simplification. As in all forms of product initiation, trade-offs have to be made throughout the design evolution activity resulting in an efficient final product. Battery charging systems do not take exception to this rule.

The objective for an optimum charging system is to charge batteries in a manner which will replenish the maximum battery efficiency, while maintaining a modest electrolyte temperature rise in an acceptable period of time. The criteria for applicable variables must rest with the system designer, as all aspect of mechanical, electrical and environmental stimuli may enchance or reduce system efficiency.

The factors which shorten battery life (a term used to denote the rated useful energy for a prescribed amount of time) for example, have generally been left up to the operator of the equipment to maintain.

Through some form of osmosis, the operator is expected to assimilate these applicable variables and make an assesment as to the depletion of his batteries.

The technological advancement of batteries has been slow, but the throughput of informative documentation has been slower. Many times the terms over-charge, electrolyte temperature, equalization, specific gravity, capacity, are not only vague, but ambiguous when presented in promotional oriented format.

Take for example the individual responsible for the requisition of batteries. He is bombarded with the terms "down to 80% of charge" or "0% of capacity", etc., all of which mean the same thing but if not properly understood could lead to eventual reclamation of purchased systems.

Inquiries have shown that the highest degree of interest relating to the power source excludes the selection of batteries. Extended periods of time are spent in the matching of equipment vs. batteries for appropriate stimuli, comparison of Lead-Acid vs. Gel-Cell, Deep-cycle vs. Automotive and ampere hour capacity. This funneling of limited interest will in short time, lead to the degradation of system efficiency. It is important to refocus the priority not just on the batteries but to the battery charger or charging system as well.

Laboratory tests on batteries have shown that as a battery charges it presents a complex change in character. These changes are not only a factor of battery capacity status, but are enhanced by the age (number of cycles) and physical condition.

The conversion from a discharged to a charged status is an accumulation of transformation properties in the PbO_2 electrodes. These morphological changes are most easily depicted by observing the battery voltage, charging current and electrolyte termperature.

Generally, Lead-Acid batteries in a discharged state, represent a predominately resistance condition. This condition remains until the Pb^{2+} ions precipitate in the surrounding H_2SO_4 and migrate to its respective Pb plate. This diffusion process is indicated by a sudden increase of interfacial or electrolyte resistance (Figure I) (A) causing sudden rise of cell voltage, along with electrolyte temperature (B).

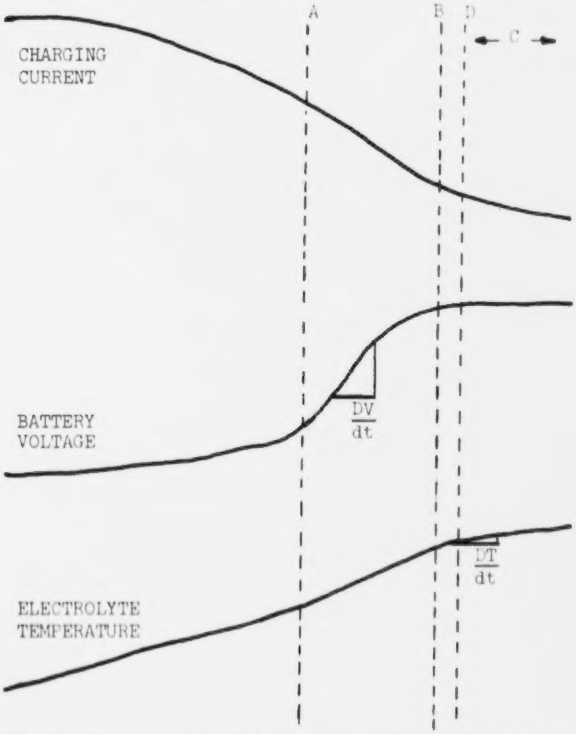
As the morphological changes within the cell structure approaches equilibrium, the resistive nature of the battery transforms to resemble a capacitive behavior (C).

A properly matched battery system must be able to react to this transformation by tailoring its charging current down to a congruent level necessary to start and complete its equalization phase, without elevating the electrolyte temperature beyond the point of simple outgas.

The proposal that the length of equalization phase has a direct influence on performance is worthwhile for discussion, for even though the voltage has stabilized to some reasonable plateau, the eccentric levels of specific gravity from cell to cell may differ which will relate in some percentage of depleted system efficiency.

Figure I indicates the charging profile of a battery.

FIGURE I



The test to confirm the proposal of equalization was conducted as follows:

A battery in reasonable good condition was subjected to an over charge state and allowed to rest until the electrolyte temperature assumed an ambient state, specific gravity readings were taken in all cells and recorded, TABLE 1, #1. The battery was subjected to a discharge rate equal to 12 AMPS until the battery voltage indicated 80% of charge.

The battery was then charged at the maximum rate as stipulated by the manufacture. Throughout this test the battery voltage was monitored every three minutes to insure placement on the graph, where cell equalization began to manifest.

10 minutes of non-incremental voltage change Figure I (D) was denoted as the start of cell equalization and cell specific gravity readings were taken, TABLE I, #2.

CELL NO.	TABLE 1, #1 - BEFORE DISCHARGE -	TABLE 1, #2 - AFTER CHARGE - (FIGURE I (D))	△
1.	1.257	1.250	-.007
2.	1.257	1.243	-.014
3.	1.252	1.241	-.011
4.	1.247	1.236	-.007
5.	1.252	1.240	-.012
6.	1.247	1.235	-.008

TABLE 1, #2 shows that concentric specific gravity levels from cell to cell would indicate a somewhat lower level of charge capacity.

To determine the effect of an equalization phase, the charging current was lowered to substantiate a decreased $\frac{DT}{dt}$ electrolyte temperature curve. Charging current was regulated to sustain a status just above outgas and maintained in this condition for 2 additional hours. Specific gravity readings were again taken at the completion of the equalization phase, TABLE II, #1.

CELL #	TABLE I #1 (Shown for clarity)	TABLE II #1	△
1.	1.257	1.258	+.001
2.	1.257	1.257	.000
3.	1.252	1.250	-.002
4.	1.247	1.246	-.001
5.	1.252	1.251	-.001
6.	1.247	1.248	+.001

Particular interest has been aimed as to the validity of the equalization phase.

Certain battery charger manufactures maintain the philosophy that by simply allowing the battery to rest until completion of the outgas process and mixing the electrolyte can accomplish the same results. Our laboratory tests have shown that although a battery at rest will acquire some degree of increased specific gravity levels along with battery voltage, the concentric differential levels of the specific gravity from cell to cell would depict a surface charge elevation, rather than a tangible increase in storage capacity.

The surface charge tends to manifest as a localized transformation of the Pb^{2+} ions in solution and will continue throughout the remainder of the outgas process due to elevated temperature of the electrolyte. If mistaken for homogeneous acid concentration throughout the cell and around the electrodes, this could appear as an unexpected decrease in storage capacity.

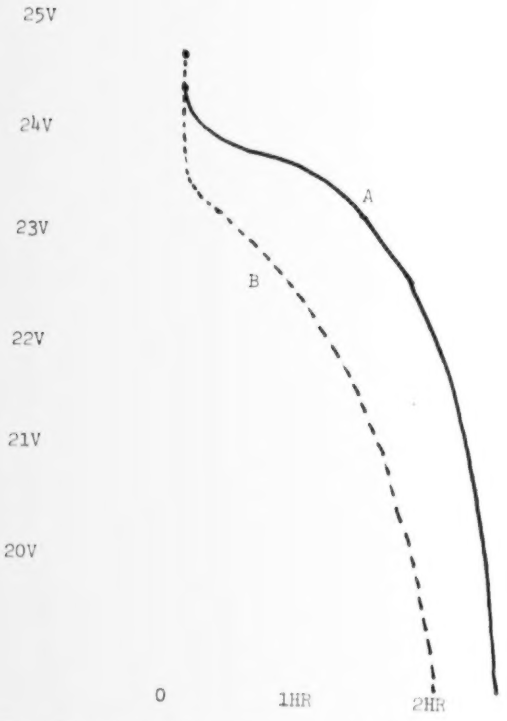
Batteries approaching their "twilight" phase usually show an inordinate level of surface charge, giving an even lower degree of equalization.

This phase of a battery's life is the most difficult to maintain. The progressive deterioration of cell plates and inability to complete the morphological transformation manifest as reduced operator functional time, i.e., range of a wheelchair, higher than normal electrolyte temperatures during charge, and an accelerated program of cell watering; all of which requires a higher degree of diligence upon the charger and the battery maintenance program.

Figure II displays the different discharge curves of two group sets of 22NF batteries (each group consist of 2 batteries in series to equal a 24V system) the graphs are superimposed on each other, and represent the system capacity in terms of hours. Graph line A, are batteries with approximately 20 charge-discharge cycles. Graph line B are batteries with approximately 300 charge-discharge cycles.

The test consisted of discharging fully charged batteries at a constant rate of 12 amps.

FIGURE II
Discharge Characteristic



The intrinsic particularities of a battery in its "Twilight Phase" is revealed within the first few minutes of discharge. It is interesting to note that two conditions are revealed. First the inordinant high level of battery voltage (surface charge) which decayed rapidly and Second, although the length of time for the batteries to reach a depleted voltage was not appreciably shortened, the level of capacity approached approximately ½ that of group A in a time vs. capacity aspect.

Equalization during the charging cycle may not, in the case of batteries in their Twilight Phase, show an appreciable effect, but will extend the usable life or longevity of new batteries if started and maintained on this concept.

Steve Brodsky, Project Engineer
Everest & Jennings Inc.
3233 E. Mission Oaks Blvd.
Camarillo, CA 93010

A New Solution to Caster Wheel Shimmy

J. J. Kauzlarich[1], Ph.D., T. E. Bruning[2], III M.S., W. G. Dimaio[3], M.S.
University of Virginia, Rehabilitation Engineering Center
Charlottesville, Virginia

ABSTRACT

The problem of caster wheel shimmy in wheelchairs has been solved through the use of dual wheels on a common axle or separated dual treads on a common wheel. Caster wheel shimmy is a self excited lateral oscillation of the caster which will occur when the wheelchair reaches a critical speed. The drag due to caster shimmy can be so great that the user can be thrown from the wheelchair. The new caster design allows the wheelchair to operate shimmy free at much higher speeds than with standard designs and does not require expensive and cumbersome damping devices.

INTRODUCTION

Caster wheel shimmy is a self excited vibration of the caster which will occur above a critical speed. Almost everyone has experienced caster wheel shimmy in grocery shopping carts or other household carts with caster wheels. The caster shimmy is annoying at best and in some cases dangerous. The resulting drag on a wheelchair due to shimmy of one of the caster wheels can cause the wheelchair to suddenly turn and throw the user out of the chair.

The problem of caster wheel shimmy has been much more important for aircraft nose wheels, and there is an extensive body of literature on the subject, e.g., (1). In the case of wheelchair caster shimmy Brearley (2) has proposed a mechanism that involves a physical model where the caster wheel pivot shaft must be inclined from the vertical in order for the caster to shimmy. Moreland (1) considers aircraft caster wheels and finds that it is not necessary for the caster pivot shaft to be inclined from the vertical in order for the caster to shimmy, and he shows that a number of experiments with aircraft caster nose wheels supports his analysis.

In 1943 Maier and Rens (3), and Schlippe and Dietrich (4) investigated caster shimmy problems in aircraft using dual wheels. They found that when the dual wheels had a common axle so they were co-rotating shimmy was suppressed. The concept of co-rotating wheels to suppress shimmy has been successfully applied to aircraft design (5), but until now has not been applied to wheelchair caster wheel design. This may be due to the fact that the design principles are very complex, and it is not obvious as to how to design the caster wheel to make a significantly improved version based on the co-rotating wheels or dual tread concept.

The purpose of this paper is to develop the concept of co-rotating treads or wheels for shimmy suppression of wheelchair caster wheels.

THEORY

In 1961 Stevens (6) published a general shimmy theory for the design of casters involving dual co-rotating wheels. As a simplification from the general theory he assumed that the tires were flexible in the vertical direction only. Moreland (7) presented a shimmy theory for a single caster wheel in which he made the same simplifying assumptions as Stevens, which he called the third order system analysis. A Schematic of the third

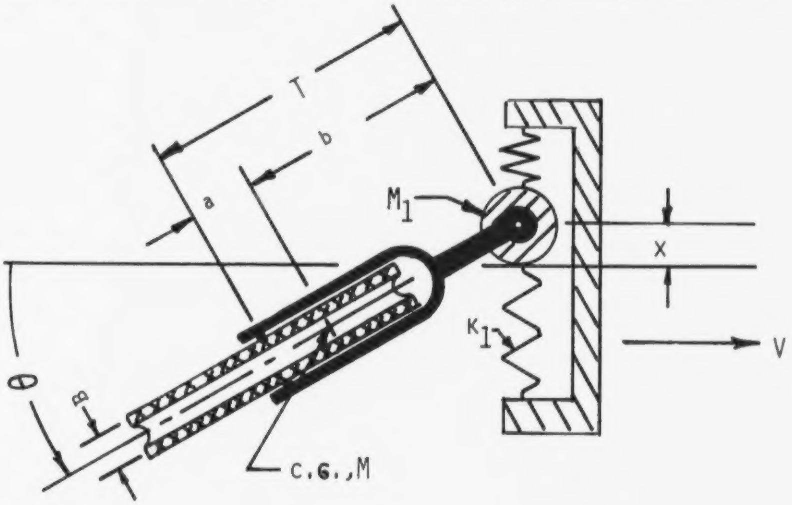


FIGURE 1
SCHEMATIC OF CASTER WHEEL ASSEMBLY

order system is shown in Figure 1. By combining results from both of these analyses, it is possible to reduce Steven's theory to the following equation for the critical shimmy velocity for dual co-rotating wheels or dual treads on a single wheel.

$$V_C = \frac{C_d\,T}{2\,I_w} + \frac{1}{2}\sqrt{\left[\frac{C_d T}{I_w}\right]^2 + \frac{2B^2 K_s T}{I_w}} \qquad (1)$$

where

V_c = critical shimmy speed, m/s

C_d = torsional damping, N-s-m

T = caster wheel trail, m

I_w = mass moment of inertia of caster wheel about its vertical axis, kg-m^2

B = separation of co-rotating tires or treads, m

K_s = tire slip coefficient, N (see definition in Ref. 6)

Equation (1) can be further simplified for two interesting cases. If the dual tire separation is reduced to zero, then we get Moreland's (7) equation for the critical velocity, where

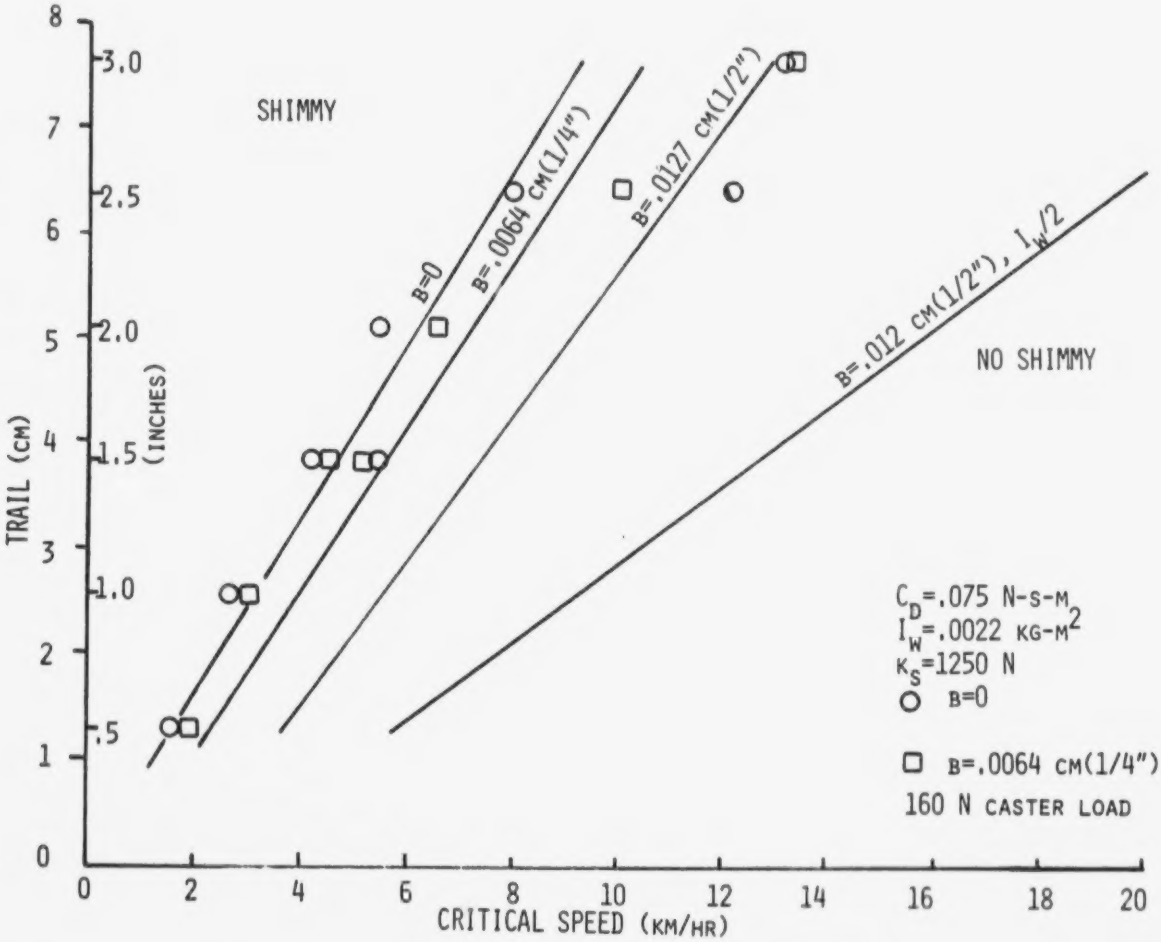
$$V_c = \frac{C_d T}{I_w} \qquad (2)$$

In the case where the torsional damping reduces to zero the effect of co-rotating wheels or treads leads to a finite value for the critical speed of

$$V_c = \sqrt{\frac{B^2 K_s T}{2\,I_w}} \qquad (3)$$

The theoretical equation (1) is approximate due to the simplifying assumptions, but is remarkably accurate for the wheelchair caster tests performed so far, and can be used in designing shimmy free caster wheels over the operating speed range of interest.

FIGURE 2
CRITICAL SHIMMY SPEED



TEST RESULTS

Two experimental caster wheels with adjustable trail forks were mounted on a test wheelchair which was towed on a treadmill. The forks pivot shaft was mounted in ball bearings and had no other damping. The wheel had a ball bearing hub, a solid gray rubber tire, and metal spokes. Figure 2 shows the experimental measurements for the speed at onset of shimmy as a function of the trail, and for two cases: (1) ungrooved tire, and (2) tire with a 1/4 inch (.0064m) wide groove. The measured parameters used in the shimmy equation are listed on Figure 2. Varying the load on the caster caused a small variation in critical speed.

The effect of increasing the groove width to 1/2 inch (.0127m) and decreasing the mass moment of inertia of the wheel by 1/2 is plotted on Figure 2. The major difference between the theory and experiment is due to variations in the torsional damping of the caster pivot bearing.

DISCUSSION AND CONCLUSION

For a caster wheel with 2 inches of trail, it is shown in Figure 2 that the critical shimmy speed can be increased by a factor of 2.7 by placing a 1/2 inch wide groove in the tire and decreasing the diametral moment of inertia of the wheel by 1/2. With the new lightweight plastics it is possible to decrease the moment of inertia without decreasing the diameter of the caster wheel resulting in a design which is shimmy free for wheelchair operating speeds. Preliminary tests support the above conclusion.

A patent application is being prepared for the new design caster wheel for wheelchairs and carts.

REFERENCES

1. Moreland, W. J., "The Story of Shimmy," J. of Aero Sciences, V21, #12, pp. 793-808, December 1954.
2. Brearley, M. N., "Investigation of Caster-Wheel Shimmy," Quart. J. of Mech. and Appl. Math., V33, #4, pp. 491-505, 1980.
3. Mair, E., and Rens, M., "Shimmying Tests on Dual Wheels I, Model Tests," ZWB (1943), Komm. Verl. Oldentourg., Berlin, Translated: ATI 22381, ASTIA, 1947.
4. Schlippe, B. Von, Dietrich, R., "Flutter of a Wheel with Pneumatic Tire," Jahrbuch d. Lute, ID:010, Translated: ATI 57160, ASTIA, 1943.
5. Livers, C. B., and Hurt, J. B., "Conquest of Nose Wheel Shimmy," Aero Digest, pp. 134-137, 226, 1944.
6. Stevens, John E., "Shimmy of a Nose-Gear with Dual Co-Rotating Wheels," J. of the Aerospace Sci. V28 pp. 622-630, August 1961.
7. Moreland, William J., "Landing-Gear Vibration," AF Tech. Report 6590, Wright Air Dev. Center, pp. 70, October, 1951.

1. Professor of Mechanical and Aerospace Engineering, University of Virginia, Charlottesville, Virginia, 22903.

2.3. Engineering Graduate Research Assistants, University of Virginia.

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5.3

THE EFFECT OF INERTIAL PARAMETERS OF CASTERS ON WHEELCHAIR CASTER SHIMMY

T.E. Bruning III M.S., J. J. Kauzlarich, Ph.D. and C. A. McLaurin, Sc.D.
University of Virginia Rehabilitation Engineering Center
Charlottesville, Virginia

ABSTRACT

The most significant results of a study of wheelchair caster shimmy are presented. This study finds that the trail and moment of inertia of the wheel are the inertial parameters of wheelchair casters with the greatest effect on shimmy.

INTRODUCTION

Shimmy is one of the more annoying problems of wheelchairs, because it causes increased rolling resistance and may lead to loss of control or structural failure of the wheelchair. A study of wheelchair caster shimmy at the Rehabilitation Engineering Center, see ref.(2), has identified inertial characteristics of the casters that contribute significantly to the tendency to shimmy.

THE NATURE OF SHIMMY

Shimmy is a self-excited vibration. This is a vibration caused by a force that is a function of the state of the system itself, rather than by an external periodic force. In the case of wheelchair caster shimmy the force is a function of the angular position of the caster, the transverse acceleration of the wheelchair frame, and the forward velocity of the wheelchair. When the caster wheel is pointed exactly in the direction of motion of the wheelchair then there is no driving force for shimmy and the caster will not shimmy. However, if there is any disturbance that causes a deviation of direction or a transverse acceleration of the wheelchair frame then shimmy may begin.

When the vibration is initiated, the amplitude will either diminish and cease or it will increase and persist. The outcome depends strongly on the velocity of the wheelchair, the torsional damping, and the inertial characteristics of the caster. Sustained shimmy occurs at higher velocities. At lower velocities the shimmy will damp out; the lower the velocity the more rapidly the shimmy disappears.

TESTS AND RESULTS

Tests were run with a specially built wheelchair tethered on a treadmill. The test wheelchair had an adjustable caster fork as shown in Figure 1 which allowed changes in the trail of the caster wheel without changing the wheelchair. Stability, or the ability to roll without shimmy, was measured by determining the critical velocity for the caster; this is the velocity below which the vibration damps out and above which the vibration is sustained. The inertial parameters included in the study were the masses and the moments of inertia of the fork and wheel, and the location of the centers of gravity of the fork and wheel with respect to the swiveling axis. This last parameter, the location of the center of gravity of the wheel, is called the trail as shown in Figure 1.

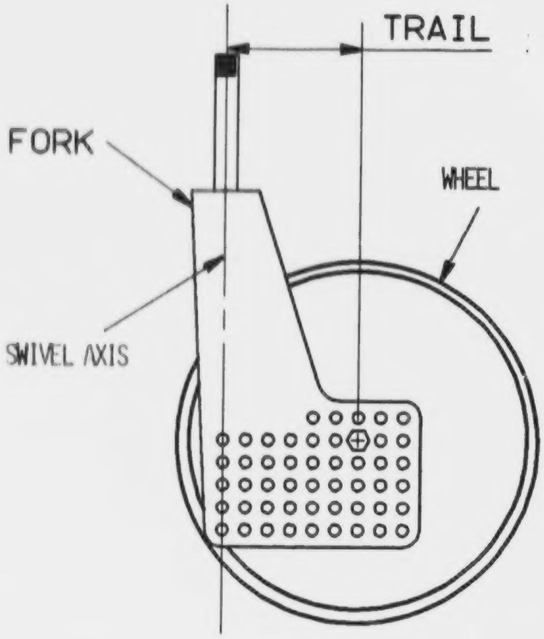

FIGURE 1: TEST FORK

The relative stability of casters depends strongly on two of the inertial characteristics of the casters. The first is the trail of the caster, and the second is the moment of inertia of the wheel about a vertical axis through its center of gravity.

In one set of tests a variety of wheels were used with the test fork shown in Figure 1. The axle of the wheels was placed in the test fork at different locations to vary the trail without changing any of the other parameters. Figure 2 shows the critical velocity as a function of trail for three different wheels. As the trail increases the critical velocity increases exponentially. The forks supplied by the manufacturers have trails between two to two and one fourth inches: at moderate walking speed, which is between one and one and a half meters per second, the two Everest & Jennings wheels are operating very close to the critical velocity. At slightly higher speed, a brisk walk or a coast down a hill, those wheels are very likely to shimmy. The Quadra wheel is sold in a fork with trail of two and a half inches; and as a result it never operates close to the critical velocity and never shimmies, a feature that makes it popular with wheelchair basketball players.

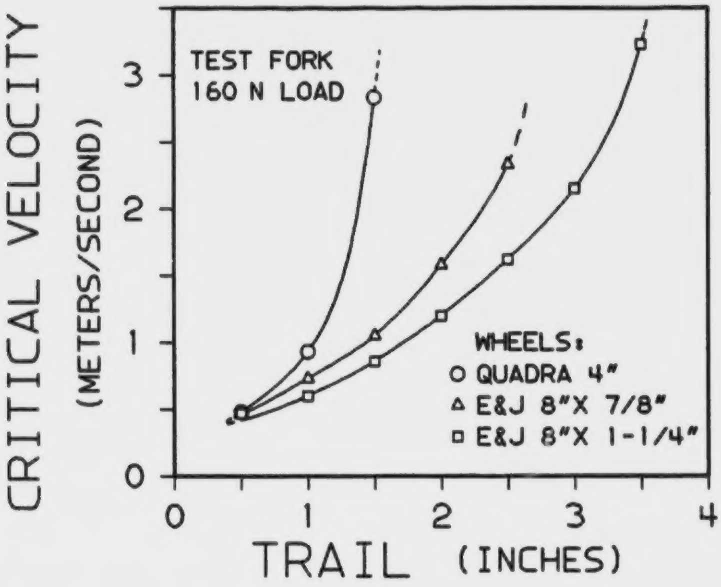

FIGURE 2: CRITICAL VELOCITY INCREASES EXPONENTIALLY WITH INCREASING TRAIL.

TABLE 1: WHEEL PARAMETERS

		(IN)	(KG)	MOMENT OF INERTIA (KG-M2)	CRITICAL VELOCITY @ 2" trail (M/S)
A	Quadra	4	.280	.18	Stable*
B	Kryptonics (MOD.)	5	.338	.33	Stable*
C	E & J (Mod.)	7	.444	1.07	2.39
D	PRC Pneumatic	8	.562	1.25	1.77
E	Stainless	8	.815	1.60	1.46
F	E & J 8 x 7/8	8	.699	2.00	1.58
G	E & J 8 x 1-1/4	8	1.380	3.42	1.20

*up to 3.8 M/S (13.7 km/hr)

In another test a variety of wheels were placed in the test fork with a trail of 2.0 inches. In Figure 3 the range of velocity for stable operation is plotted for the wheels in Table 1 against the moment of inertia of the wheel. For wheels A and B there was no tendency to shimmy at the maximum treadmill velocity of 3.8 m/s. The critical velocity tends to be higher for wheels with lower moment of inertia. These are the wheels with smaller diameter and least mass as seen in the Table, because these characteristics contribute to a smaller moment of inertia.

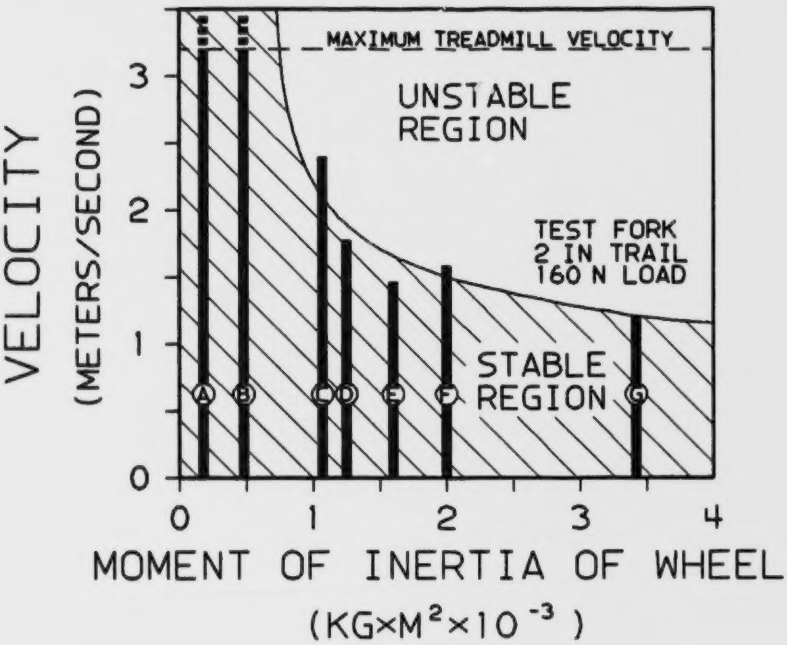

FIGURE 3: CRITICAL VELOCITY IS HIGHER FOR WHEELS WITH LOW MOMENTS OF INERTIA.

DISCUSSION

For the tests just described and for similar tests investigating the effect of the other inertial parameters, the values for the parameters were varied across a range that includes all wheelchair casters in current use. Within that range only the trail and moment of inertia of the wheel, of the six inertial parameters investigated, significantly contributed to the stability of the caster.

There are, however, numerous non-inertial factors which affect stability. The load on the caster, the shape and composition of the tire, and the fit and drag of the bearings are among the list of additional factors that affect stability. In some instances these may overshadow the effect of the inertial parameters. As a result, testing and design of casters must consider these factors as well as the inertial parameters.

CONCLUSION

Two inertial parameters of wheelchair casters, the trail and moment of inertia of the wheel, strongly influence the tendency of the caster to shimmy. Careful attention to the values of these parameters enable the design of a caster that will not shimmy in everyday use. Resistance to shimmy is enhanced by maximizing the trail and minimizing the moment of inertia of the wheel.

REFERENCES

1. Brearly, M.N., "Investigation of Castor-Wheel Shimmy," Q. Jl. Mech. Appl. Math, Vol. XXXIII, Pt. 4, 1980.

2. Bruning, Theodore E. III, "Investigation of Wheelchair Caster Shimmy," Master's Thesis, University of Virginia, May 1982.

3. Moreland, William J., "Landing Gear Vibration," AF Tech. Rep. No. 6590, Wright Air Dev. Center, U.S. Air Force, Oct. 1951.

4. Moreland, William J., "The Story of Shimmy," Journ. Aero. Sci., Vol. 21, No. 12, Dec. 1954, pp. 793-808.

5. Smiley, Robert F., "Correlation, Evaluation, and Extension of Linearized Theories for Tire Motion and Wheel Shimmy," NACA TR 1299, 1957.

1. Project Engineer for IBM Corporation in Tucson, Arizona.

2. Professor of Mechanical and Aerospace Engineering, University of Virginia, Charlottesville, Virginia, 22903

3. Engineering Director of Rehabilitation Engineering Center, University of Virginia, Charlottesville, Virginia 22903.

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A CAD APPROACH FOR OPTIMAL DESIGN OF A WHEELCHAIR FRAME - A PRELIMINARY REPORT

5.4

Ray Vanderby, Jr., Ph.D.   Avinash G. Patwardhan, Ph.D.

RR&D Center, Hines VA Hospital, Hines, Illinois 60141
Dept. Orthopedics, Loyola U. Medical Center, Maywood, Illinois

INTRODUCTION

In 1976 the Veterans Administration spent approximately $3.5 million on standard manual wheelchairs, and $1.0 million on powered wheelchairs for veterans. Some data are available on the repair and maintenance rates. Silverman (2) examined retrospective repair records of manual wheelchairs repaired at one facility for four years. It was found that 80% of the repairs involved tires, upholstery, and bearings, and that the average number of repairs was 2.4 in seventeen months. Roeper and Silverman (1) have also studied the repair rates of powered chairs. During the one year of study, chairs were brought in for repairs an average of 8.7 times. The weight bearing system, especially tires and tubes, accounted for the majority of repairs. The survey also showed a great concern towards the weight of the chair. The above reports point out two basic areas in which significant functional improvement can be achieved, namely the structural strength of the frame and its weight. Past laboratory studies have compared the strength and weight of several powered and manual chairs and shown that the strength to weight ratio can be improved through use of stronger and light weight materials. However, there is little data available on the optimal utilization of material as it applies to the structural design of a wheelchair frame.

With the advent of interactive computer techniques, it is now possible to integrate the sophisticated finite element method (FEM) of structural and stress analysis with optimization algorithms to arrive at the best possible design of a system subject to a set of criteria. This work is a step towards utilizing such a computer aided design (CAD) package to arrive at the optimal design of a wheelchair subject to a criteria such as the strength/weight ratio, the ride comfort in a chair with a suspension mechanism, and so on. This paper presents the capabilities of the FEM in analyzing the static and dynamic performance of a typical wheelchair frame.

METHODS

A CAD package from ALGOR Inc. is used to investigate a standard wheelchair frame augmented with additional suspension elements. The package is composed of a model builder pre-processor module, a FE analysis module based primarily upon the commonly used SAP IV linear elastic code, and a post-processor module for aid in interpretation of the analytical results.

The model is composed exclusively of standard three-dimensional beam elements. Fig. 1 shows the element numbering for this model. The majority of these elements have sectional properties to model a 7/8 in. tube with 1/16 in. wall thickness. The cross member elements (55-58) are modeled as 1 in. tubing with 1/16 in. wall thickness. Elements 26,27,53, and 54 are special beam elements with reduced axial stiffness to account for the suspension system elements in the model. All intersection points of the cross-members have their appropriate degrees of freedom released to simulate the pinned connections that physically exist in a standard collapsing wheelchair. Boundary conditions consist of a horizontal constraint in the direction of chair movement at the front wheel attachment points, a horizontal constraint orthogonal to the direction of chair movement at the cross-member intersection, and vertical constraints at the attachment points of the four wheels.

Three analyses were run with this model including static, modal, and transient. The static analysis simulates an 80 kg person at rest in a wheelchair. In this simulation, load is assumed to be uniformly distributed over elements 19-22 and 46-49.

Modal analysis is commonly used to analyze suspension systems. It calculates vibrational mode shapes and natural frequencies of the dynamic system. These can, in turn, be analysed to see if there could be any undesirable coupling of these vibrational modes with external forcing functions such as ground irregularities during forward motion or the vibrations of a power unit. The model for this example case includes solution of the homogeneous differential equation. That is, no forcing functions are considered.

The transient analysis presented here is an example of CAD capabilities and does not consider all possible dynamic loading conditions. The dynamic forcing function used here applies a spike of vertical acceleration to first the front wheels and 0.25 seconds later to the rear wheels. This spike increases linearly over .01 seconds from 0 to 1 g, and decreases linearly back to zero over the next 0.01 seconds. Internal forces and moments are computed throughout as transient functions and their maximum values are retrieved.

RESULTS AND DISCUSSION

Results of these analyses are given in fig. 2-5 and Tables 1-3. Fig. 2 and 3 show the deformation of the frame caused by previously described static loading. Note the scissors action expansion of the chair in fig. 3. Such motion produces an undesirable loading on the rear wheels and bearings. Selected element internal forces are listed for this case in Table 1. These represent the elements with the highest internal stress producing forces. The internal stresses can be computed from these forces using the known dimensions of the members. Elements on only one side are listed since the behavior is nearly symmetrical for this type of loading. It is observed here that for the selected static loading case, the maximum stress in the critical elements (Table 1) is below 3000 psi, which is well within the safe working limits of the material used in a standard wheelchair. This suggests a strong likelihood of a redesign of the frame for weight reduction. However, it should be noted that one would have to analyze the complete spectrum of possible loading conditions before arriving at the final redesign recommendations.

Table 2, and fig. 4 and 5 show the results of the modal analysis. Note here that the natural frequencies of this system are quite low. They are in a range where there is a strong likelihood that they could be excited during normal use. This may become important in a sports environment where significant dynamic excitations are expected. Table 3 lists the internal forces acting on selected elements. In this case these represent the variation of the maximum absolute values of the internal forces with respect to time. It can be observed that the stresses due to the transient load (described above) are quite low (lower than the static analysis forces). Thus, the summation of these stresses representing the combined effect of static and dynamic loading is still well below the strength of the frame tubing. Although this is an example case of a somewhat artificial transient loading, it nevertheless identifies design areas with potential for weight reduction without compromising the structural integrity of the wheelchair frame.

In summary, this paper presents a methodology of utilizing a FEM to analyze the structural behavior of the wheelchair frame with the goal of identifying potential areas of redesign.

REFERENCES

1. Roeper,P. and Silverman, H.J.: An analysis of repair records of powered wheelchairs. Berkeley, CA Center for Independent Living., 1978

2. Silverman, H.J., et al: Economic costs of manual wheelchair repairs: an analysis of repair records. Berkeley, CA Center for Independent Living., 1979

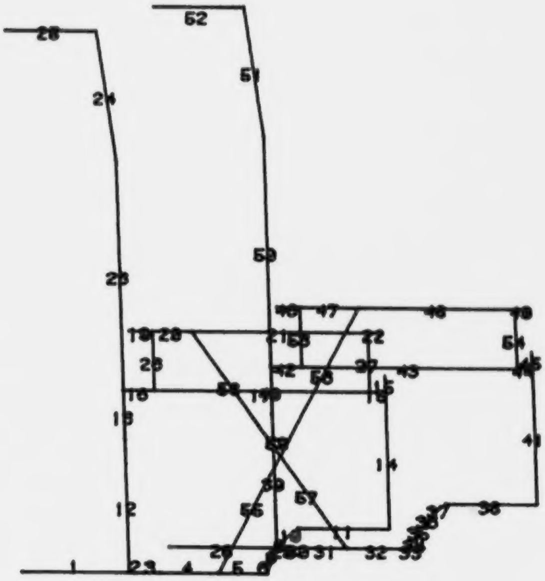

Fig.1. An oblique view of the wheelchair with the elements numbered.

TABLE 2: PARTIAL RESULTS OF MODAL ANALYSIS

Mode Number	Circular Frequency (Rad/Sec)	Frequency (Cycles/Sec)	Period (Sec)
1	7.3	1.1	.8596
2	36.1	5.7	.1783
3	54.5	8.6	.1152
4	66.4	10.5	.0945
5	705.3	112.3	.0089

Table 1: SELECTED ELEMENT FORCES FOR STATIC LOAD CASE

Element Number	Axial Force	Bending About Y	Bending About Z
16	1.98	-0.29	-18.30
	-1.98	-0.74	-60.60
20	29.75	0.64	-56.99
	-29.75	1.32	-10.99
21	30.67	2.30	- .63
	-30.67	0.52	78.40
26	40.44	3.26	-50.89
	-40.44	-4.18	-51.36
27	40.44	1.78	29.54
	-40.44	- .93	75.90

Table 3: SELECTED ELEMENT FORCES FOR TRANSIENT LOAD CASE

Element Number	Axial force	Bending About Y	Bending About Z
16	0.69	0.01	6.15
	0.69	0.11	12.44
20	2.33	0.09	0.65
	2.33	0.07	1.17
21	2.33	0.26	1.69
	2.33	0.19	0.67
26	9.82	0.99	7.35
	9.82	1.02	0.65
27	9.83	0.37	8.70
	9.83	0.23	0.67

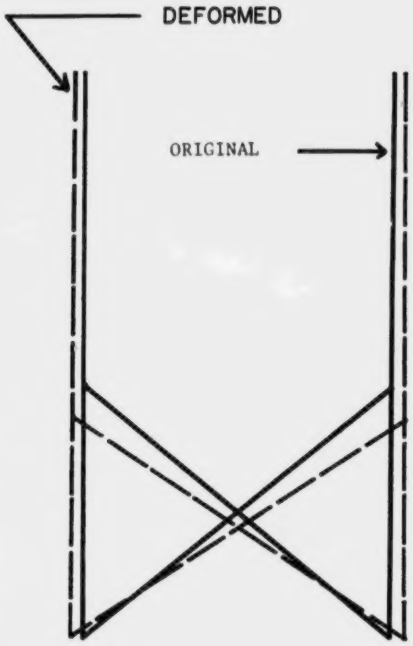

Fig. 2. Front view of the chair showing its deformed shape.

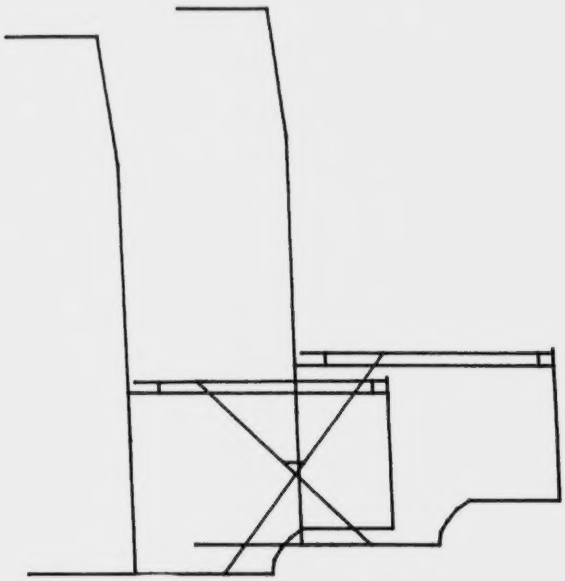

Fig. 4. First vibrational mode shape of the frame showing primary deformation in suspension elements.

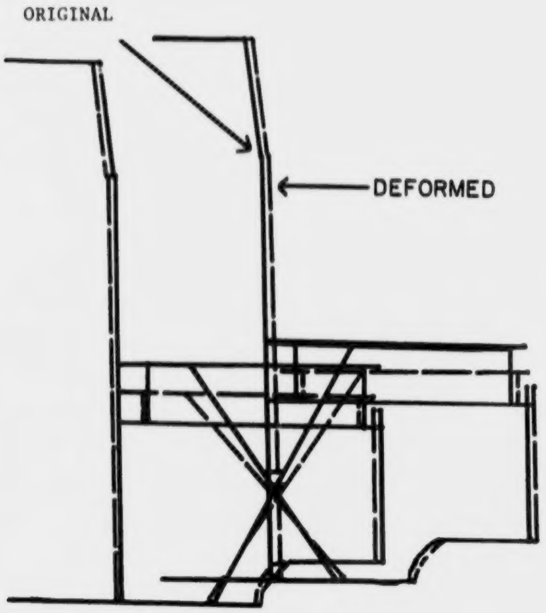

Fig. 3. Oblique view of the chair showing its deformed shape after static loading.

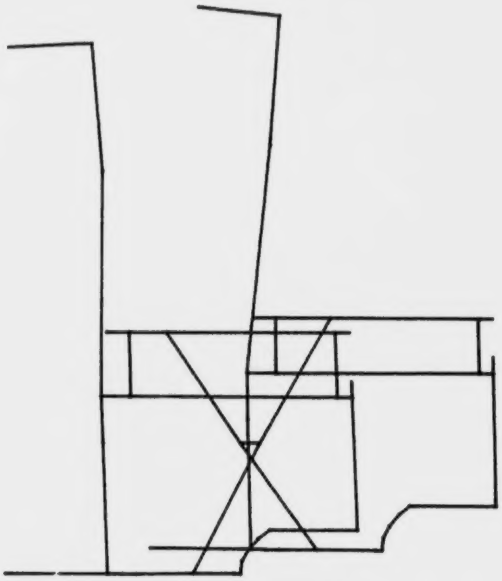

Fig. 5. Second vibrational mode showing primary deformation in the back support elements.

ANALYSIS OF A MANUAL WHEELCHAIR SUSPENSION SYSTEM

J.G. THACKER PhD

University of Virginia Rehabilitation Engineering Center
Charlottesville, Virginia

ABSTRACT

Modeling of wheelchair suspension systems to investigate ride comfort is described using a comfort index. Parameters investigated are suspension geometry and damping parameters. Two cases are investigated; torque input disturbances and surface disturbances. It was found that optimum values can be predicted for the two cases. Propulsion efficiency is also investigated and found not to be adversely affected by the addition of suspension systems to manual wheelchairs.

INTRODUCTION

The addition of spring suspensions to the rear wheels of manual and powered wheelchairs is thought to produce a more comfortable ride. Stout reports [1] that as a result of adding a spring link suspension to a wheelchair rider comfort is improved, driver fatigue is reduced and ground seeking is enhanced. Before a prototype wheelchair is built it is necessary to perform a dynamic analysis on the motion characteristics of the suspension system in order to determine the most likely stiffness and damping ratios to produce the most comfortable rides. This paper describes the method of determining how these design parameters were chosen with the intention of optimizing ride quality.

Several problems arise when adding suspensions to wheelchairs and must be adequately studied. The efficiency of propulsion might be compromised also due to excessive chair pitching during acceleration caused by the non constant input torque. Stout also sites that tipover stability might be affected due to the shifting of the center of gravity.

MATERIALS AND METHODS

Ride quality is very difficult to define on a quantitative basis. The method adopted in this study is one described by Jacobsen et. al.[2] in which ride quality is defined as a function of several kinematic and physical parameters. A ride quality numerical index was predicted from the following physical variables:

RMS Longitudinal Acceleration AL (g)
RMS Vertical Acceleration AV (g)
RMS Roll Rate WR (rad/s)
RMS Pitch Rate WP (rad/s)

The ride quality index was developed by correlating passenger ratings for ground based vehicles to the above physical variables. The correlation results in an equation which produces a comfort index which ranges in a numerical value from 1 to 7. The rating scale is illustrated in figure 7.The comfort equation used is given as follows:

$$C=0.20WR+0.14WP+10.15AV+7.71AL+1.36$$

In order to determine the values of the four physical variables found in the comfort equation, a simulation of the wheelchair motion was performed. A lumped parameter model of the rider-system was used in the study as shown in figure 1. The magnitudes of the physical parameters appearing in the comfort equation were associated with the center of gravity of the wheelchair frame and rider. The dimension and mass values used in the model were taken from a Rolls Standard manual wheelchair and an anthropometric model of a male (68 kg) taken from Dempster [3]. The placement of the suspension pivot point was determined by Stout's analysis to be referenced to the neutral squat and dive plane and shown in figure 2 [1]. The analysis was performed for 0, +5, and -5 degrees squat and dive. The height of the pivot point remained constant at 0.395 m.

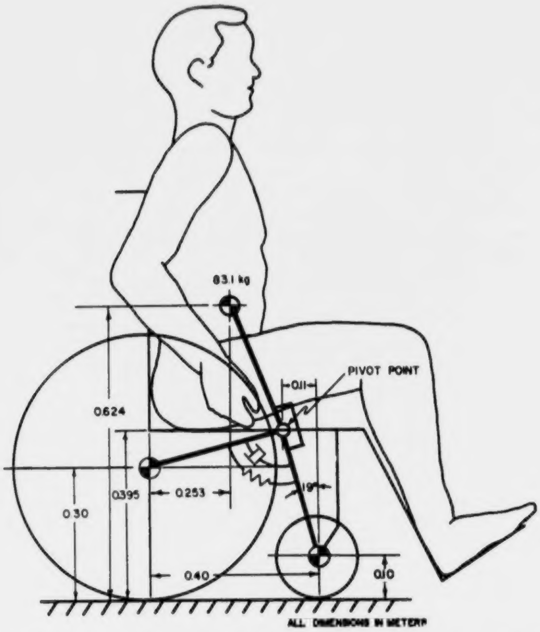

FIGURE 1 The two degree of freedom lumped mass model of a wheelchair and rider

The suspension consisted of a link with one end pivoting on the chair frame and the other end rotating on the rear wheel axle. A torsional spring and damper was placed between the pivot link and the frame. The wheelchair frame and wheels were assumed to be rigid with all deformation taking place at the suspension pivot. A periodic torque (T = 1.25 s) was applied to the rear wheel that matched experimental data taken by Brubaker [4]. Rolling frictional drag forces were applied to the wheels that matched experimental data taken at the UVa REC.

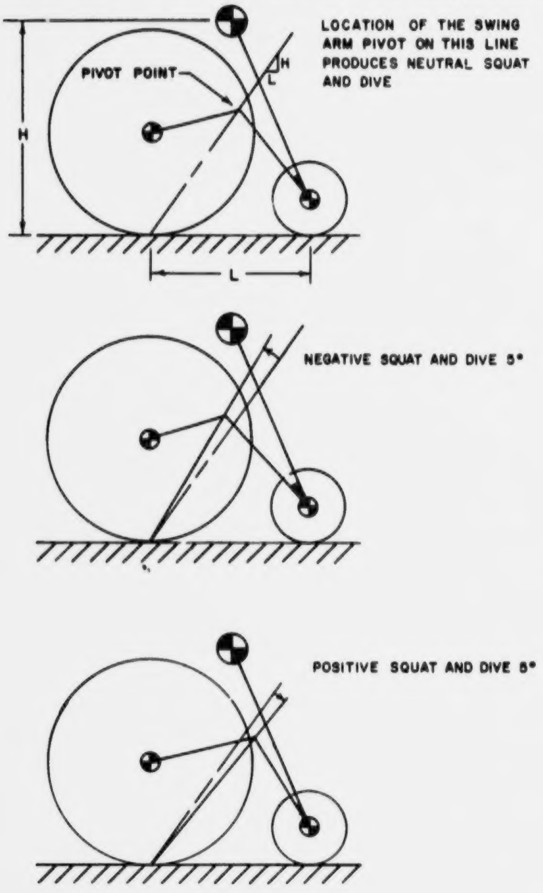
LOCATION OF THE SWING ARM PIVOT ON THIS LINE PRODUCES NEUTRAL SQUAT AND DIVE
PIVOT POINT
H
L
H
L
NEGATIVE SQUAT AND DIVE 5°
POSITIVE SQUAT AND DIVE 5°

FIGURE 2 The location of the neutral squat and dive lies on the line of slope H/L.

The wheels were assumed to always remain in contact with the floor resulting in a two degree of freedom system with a periodic exciting torque. The equations of motion were derived and found to be extremely non-linear. They were solved numerically using a forth order Runge-Kutta integration technique.

Maximum and RMS vertical and horizontal accelerations and jerks and maximum and RMS roll and pitch rates were calculated along with the comfort index as the rear wheels rode over a smooth surface and as they rode over a 3.18 mm (1/8 in) high bump at a speed of 6 km/hr. The analysis computed the above quantities as the magnitude of the spring constant and damping constant varied from 100 Nm/rad to 900 Nm/rad and 3 Nms/rad to 1000 Nms/rad respectively. Values were calculated for one torque cycle with the wheelchair initially starting at rest for the smooth surface.The chair was started at 6 km/hr for the analysis when the chair rode over the bump. In addition, an efficiency was calculated based on the distance the chair traveled over a flat surface with a specified number of torque cycle inputs. The distance traveled by the suspension model was compared to the distance traveled by a rigid model of the same dimensions. The efficiency was equal to the ratio of the two distances.

RESULTS

Overall efficiency was first evaluated as shown in figure 3. As the number of consecutive torque input cycles are increased beyond five, the efficiency increases to values greater than 90 percent of the unsprung chair. The suspension chair is not as efficient as the rigid chair during the first few torque inputs because of the initial vibration transients. During propulsion over a smooth surface,all three squat and dive geometries indicated a pronounced undesired efficiency for the systems with spring constants less than 200 Nm/rad when the damping constants were less than about 30 Nms/rad, figures 4,5 and 6. In all cases the damping constant should be above 100 Nms/rad. Some small amount of negative squat and dive seem to increase the efficiency by a small amount.

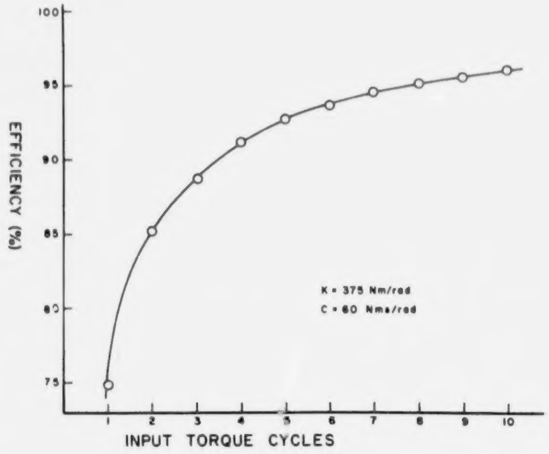

FIGURE3 Efficiency of a suspension wheelchair as the number of consecutive power strokes increases.

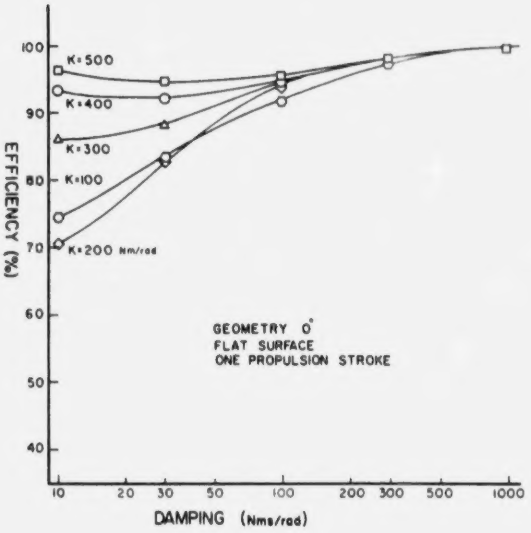

FIGURE4 Efficiency of a suspension wheelchair with the pivot placed at the neutral squat and and dive position.

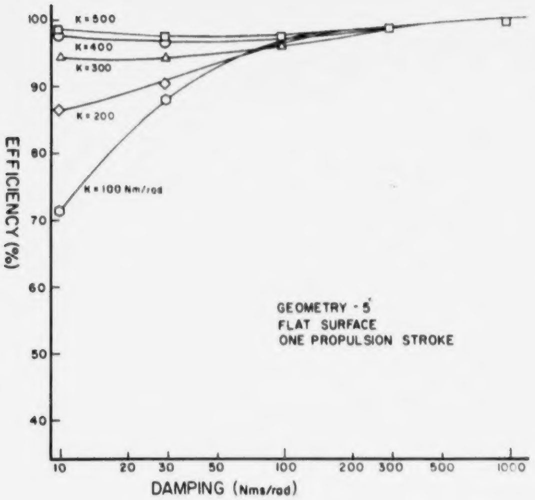

FIGURE 5 Efficiency of a suspension with the pivot placed at the -5 degree position.

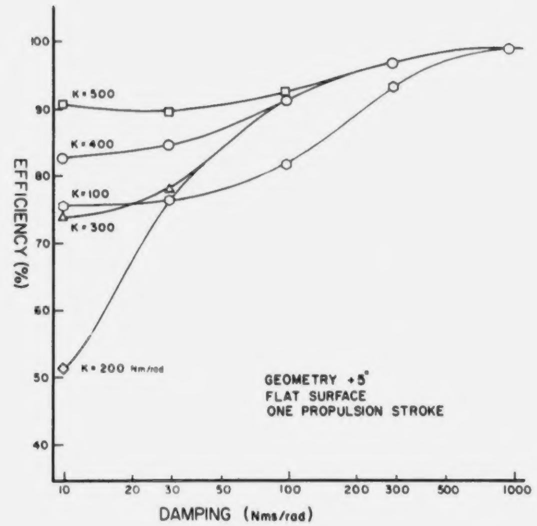

FIGURE 6 Efficiency of a suspension with the pivot placed at the +5 degree position.

The comfort index for the wheelchair system with 0 degree squat and dive for one torque cycle as it rides over a smooth surface is shown in figure 7. The rolling drag was taken to be 2.395 N with 0.500 N acting on the rear wheel. As expected, low values for both the damping and spring constant produced high comfort indicies (uncomfortable rides). Damping values less than 30 Nms/rad appear to be undesirable as with spring stiffnesses under 400 Nm/rad.

Figure 8 shows the comfort of the wheelchair system as the rear wheel coasts over a 1/8 in (3.18mm) high bump at a velocity of 6 km/hr. The optimum values for the damping constant was between 30 and 100 Nms/rad. The optimum spring constant was 100 Nm/rad.

DISCUSSION

The problem of designing a wheelchair suspension system becomes one of compromise. Uneven riding surface conditions at moderate speeds result in rather high frequency input disturbances to the system. The input torques from the user produce rather low frequency input disturbances to the system. The designer must choose parameters that obtain the best performance under both conditions. Obviously the best design will not optimize either of the individual conditions.

The ride comfort index has been supported with preliminary investigations involving human subjects riding wheelchairs in the laboratory.

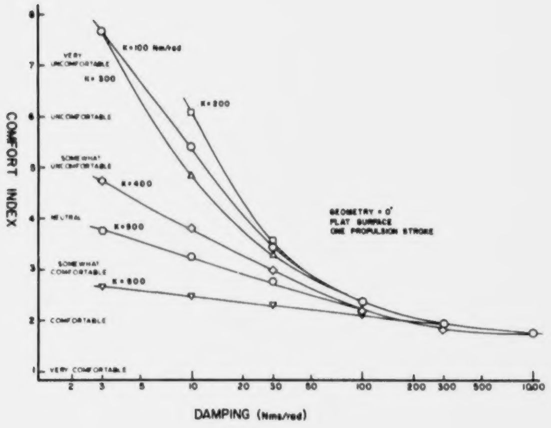

FIGURE 7 Wheelchair comfort with one propulsion stroke while riding over a smooth surface.

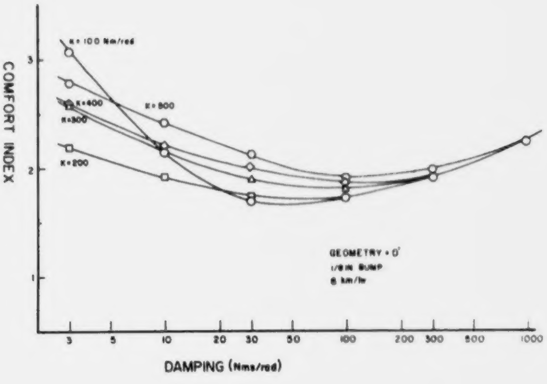

FIGURE 8 Wheelchair comfort as the rear wheel rides over a 1/8 in. bump at 6 km/hr.

CONCLUSION

Modeling of wheelchair suspension systems to study ride comfort is rather complex. The wheel chair model was a two degree of freedom lumped parameter system with a periodic torque input. The comfort model is based on studies taken from individuals while riding ground based vehicles. The three parameters that have the greatest influence on this ride comfort model were squat and dive angle, spring constant, and damping constant. The study indicates that a compromise must be made when designing for comfortable rides over rough surfaces with manual chairs. In all rear wheel swing suspension designs the pivot point of the swing link should lie on the neutral squat and dive axis. For the Rolls Standard Wheelchair model, the best parameters to use would be a damping coefficient of 100 Nms/rad and a spring constant of 200 to 300 Nm/rad. This would produce a comfort index between 2 and 3 for low frequency drive torque disturbances and high frequency bump disturbances. The study indicates that a dynamic study of any proposed suspension design can save the designer time when building and testing prototype models.

BIBLIOGRAPHY

1.Stout,G.,"Some Aspects of High Performance Indoor/Outdoor Wheelchairs",Bulletin of Prosthetic Research, 10-32, Fall 1979, p.135-175.
2.Jacobsen,I.D.,Richards,L.G.,and Kuhlthau,A.R., "Models of Human Comfort in Vehicle Environments",Human Factors in Transport Research,Academic Press, London, p.25-32.
3.Dempster,W.T.,"Space Requirements for the Seated Operator",Wright Patterson Air Force Base, Ohio, (WADCTR 55-159), 1955, p.125-155.
4.Brubaker,C.,"Wheelchair Propulsion Studies", University of Virginia Rehabilitation Engineering Center Annual Report- 1979, p. 7.
5.Stengle,G.,"A Dynamic Analysis of a Spring Suspension Wheelchair",Masters Thesis, School of Engineering and Applied Science, University of Virginia, January 1982.

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Dr. John G. Thacker
Dept. of Mechanical and Aerospace Engr.
University of Virginia
Charlottesville, Virginia 22901

5.6

LEVER PROPULSION IN WHEELCHAIR PERFORMANCE

C.E. Brubaker, Ph.D., I.S. McClay, RPT, and C.A. McLaurin, Sc.D.
University of Virginia, Rehabilitation Engineering Center
Charlottesville, Virginia

ABSTRACT

Wheelchair propulsion efficienty was measured for eight active male wheelchair users including seven paraplegics with lesions from T6,7 to L5,S1 incomplete and one high AK unilateral amputee. The means of age and weight for this group were 28.3 ± 1.4 years and 69.4 ± 5.0 Kg, respectively. They performed series of 4-minute bouts of simulated wheelchair propulsion with levers on a motor-compensated wheelchair dynamometer. The simulated conditions included bouts at nominal speeds of 2.3, 4.7, 7.0 and 9.3 Km/Hr with corresponding power outputs of 10, 20, 30, and 40 watts with 0.3M levers. Additional bouts were performed at speeds of 4.3, 7.0 and 9.3 Km/Hr with 0.25M levers, at 4.3Km/Hr with 0.45M levers, and at 4.3Km/Hr at power outputs of 31 and 42 watts with 0.35M levers. Each of these conditions was performed with gear ratios of 1:1,1.6:1 and 2:1. Comparisons of the various conditions revealed that higher performance efficiencies were consistent with higher gear ratios, with shorter levers and with higher torques. The values of efficiencies obtained were uniformly higher (and in some instances more than twice as high) than efficiencies reported in the literature for rim propulsion under comparable conditions. The highest mean efficiency, 16.33 +/- 0.77%, was obtained for the simulated condition of 4.3Km/Hr at a 2 degree incline.

INTRODUCTION

The conventional wheelchair provides mobility for over a million disabled individuals. In the course of development it has been improved with respect to weight, durability, comfort, maneuverability and folding. Dispite these many improvements the basic wheelchair remains a remarkably inefficient device. The efficiency for propelling a conventional wheelchair in typical use has been determined by a number of investigators to be in the range of 4 to 6 percent (1,2,3). Other investigations have demonstrated that propulsion efficiency is measurably increased when propelling the wheelchair up an incline or by increasing the torque-to-speed ratio in simulated performance (3,4,5). Further evidence that mechanical advantage is a determinant of efficiency is based on the performance of wheelchair athletes. While there is presently no data to quantify the propulsion efficiency of wheelchair distance athletes, it can be estimated from data on rolling resistance and aerodynamic drag measured for a wheelchair characteristic of the type used in wheelchair racing (6), and from data on maximum work rate for elite athletes (6,7). These data would suggest efficiencies in the range of 16 to 20 percent. These levels of performance undoubtedly are due to a combination of factors which would likely include the optimization of position, weight reduction, training, and the use of appropriate mechanical advantage. A typical ratio of wheel-to-rim diameters used in wheelchair racing is 1.9:1, while the common ratio for conventional wheelchairs is less than 1.1:1.

There is also considerable evidence that propulsion efficiency can be enhanced through the use of levers and cranks (3,8,9). The present study was conducted to determine the efficiency of lever propulsion of wheelchairs with respect to mechanical advantage.

METHODS

The subjects who participated in this study included seven paraplegics with spinal cord lesions ranging from T6,7 to L5, S1 and one high AK amputee. All were males who agreed to participate after receiving a full explanation of the potential risks involved. The ages, weights, and disabilities for these subjects are included in Table 1.

SUBJECT DATA

Number	Weight(Kg)	Age(Yrs)	Disability
1	48.0	20.0	L5,S1 Inc
2	52.6	25.8	AK
3	69.3	30.1	T9,10
4	95.0	31.3	T6,7
5	74.5	28.2	T11,12,21
6	68.0	27.5	T8,9
7	79.0	33.4	T11,12
8	64.0	30.1	T12 Inc
	69.4 ± 5.0	28.3 ± 1.4	

Each subject participated in three series of four-minute bouts of simulated lever propulsion. These series were conducted with gear ratios of 1:1, 1.6:1 and 2:1. Each series included nine exercise periods separated by intervals of rest. The propulsion conditions included nominal speeds of 2.3, 4.7, 7.0 and 9.3Km/Hr with corresponding power outputs of 10,20,30 and 40 Watts (W) with 0.35M levers; speeds of 4.7, 7.0 and 9.3Km/Hr with 0.25M levers; at 4.7Km/Hr with 0.45M levers; and at 4.7Km/Hr and power outputs of 31 and 42W with 0.35M levers. The order of testing was randomized with respect to both gear ratio and propulsion condition. The rest interval between successive bouts was based on post-exercise heart rate recovery to within 10 beats/min of the pre-exercise rate.

The testing was done on a motor compensated dynamometer under conditions of constant torque. Dynamometer torque, velocity, and lever torque were sampled independently for both left and right sides for 10-second intervals during the 4th minute of exercise by means of an on-line computer and stored on diskettes. The oxygen consumption (VO_2) and related ventilation parameters were determined at one-minute intervals during exercise with a Beckman Metabolic Measurement Cart (MMC). Propulsion efficiency was calculated according to customary methods from the VO_2 and the power output determined during the 4th minute of exercise.

ANALYSIS

Regression analysis to determine the curve of best fit was conducted for each gear ratio and each set of related conditions. The raw data and regression curve for each set of conditions were plotted. The polynomial and standard error of estimate for each regression were determined.

RESULTS

The results of the comparisons among the different conditions for the three gear ratios are presented in Figures 1-4. From an inspection of these four graphs it is apparent that propulsion efficiency increases correspondingly with increased gear ratio over the range investigated. The order of fit and standard error of estimate for the curves in Figures 1-4 are presented in Table 2.

FIGURE 1

MA AND EFF, V = 4.7 TO 9.3, RAD = .25M

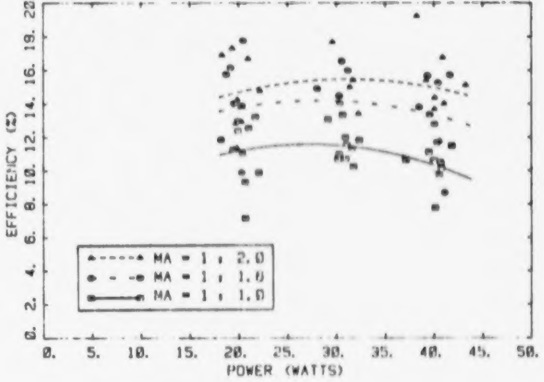
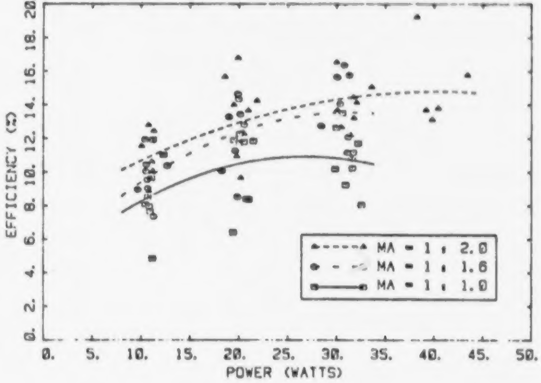


FIGURE 2

MA AND EFF, V = 2.3 TO 9.3; RAD = .35M



SUMMARY OF POLYNOMIALS AND
STANDARD ERRORS OF ESTIMATES
FOR THE CURVES IN FIGURES 1-4

	Gear Ratio	Polynomial Order	Standard Error of Estimate
	2:1	2	2.14
Fig 1	1.6:1	2	2.35
	1:1	2	1.62
	2:1	2	1.94
Fig 2	1.6:1	2	1.92
	1:1	2	2.05
	2:1	2	2.07
Fig 3	1.6:1	2	1.71
	1:1	2	1.83
	2:1	1	2.41
Fig 4	1.6:1	1	2.35
	1:1	1	2.02

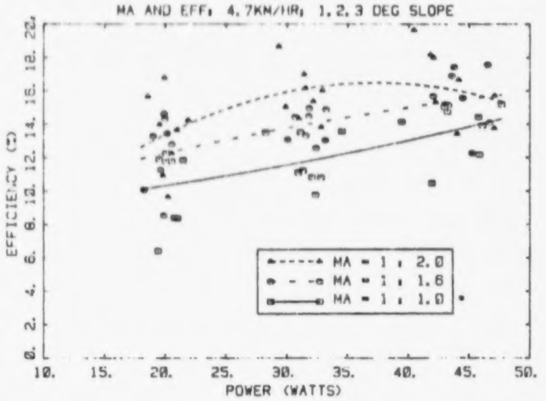
A comparison of the respective gear-ratio curves in Figures 1 and 2 shows that the efficiencies are slightly higher by approximately 1% (net) when the shorter (0.25M) radius levers were used.

It is further evident that the peak efficiencies as indicated by the regression lines, occur at respectively lower power settings for lower gear ratios, with the highest efficiency for the simulated level propulsion occuring at a gear ratio of 2:1 and 0.25M levels at a power output on the order of 33W (and speed of approximately 7.0Km/Hr.).

The highest efficiency, approximately 16.5 percent, may be found in Figure 3 for the 2:1 gear ratio. This efficiency appears to peak at a power output of about 38W. Further inspection of Figure 3 reveals that the curves become flatter with decreasing gear ratio, resulting in a greater slope at higher power settings. It may be seen that the slope of the 2:1 ratio curve becomes negative at about 38 watts, while the slope of the 1.6:1 curve remains positive in the range of the data but decreases, and the slope of the 1:1 curve is positive and increasing in magnitude through the range of the data.

FIGURE 3

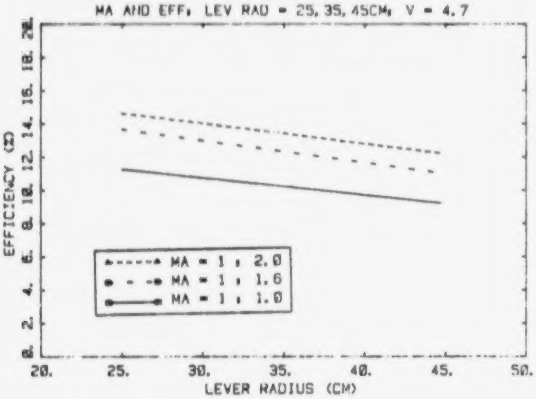
MA AND EFF, 4.7KM/HR, 1,2,3 DEG SLOPE



The effect of the three lever lengths on efficiency for propulsion at 4.7Km/Hr (approximately 20W) on a simulated level surface is illustrated in figure 4. An examination of This graph reveals an inverse relationship between lever length and efficiency for all these gear ratios that is consistent with the trends evident in Figures 1 and 2. These curves appear to be quite linear in the range of the data which is consistent with the first-degree polynomial fit for these curves.

FIGURE 4

MA AND EFF, LEV RAD = 25,35,45CM, V = 4.7



DISCUSSION

The uniformity of the results presented in Figures 1-4 demonstrates a definite, direct relationship between propulsion efficiency and gear ratio. These results are consistent with those in other studies which have dealt with mechanical advantage and efficiency (5,8,9). While the differences in efficiency associated with the different lever lengths are relatively small and are not significant due to the variability of the data, evidence of the effect of lever length is clearly shown in Figure 4. Shortening the lever radius has a simular effect to increasing the gear ratio, however, it also has the effect of changing the seat-to-lever position relationship and forcing the hand through a smaller radius arc. The latter effect would induce more sinusoidal motion for the same absolute chord displacement. It can be argued that further decrease in lever length would eventually lead to a decreased stroke (hand) displacement and excessive sinusoidal motion which should begin to decrease efficiency at some point. On the basis of these effects one would predict a reversal in the slope of the efficiency curves in Figure 4 at some point if the lever radius were further decreased. This is in agreement with Engel at al (9).

The highest point on the curves in Figures 1-4 occurs in Figure 3 for the 2:1 gear ratio. This point is coincident with a power output of 38W which simulates a condition of propelling a wheelchair up a 2-degree incline (an increased torque to speed ratio). This would suggest that still higher efficiencies would result from greater (than 2:1) gear ratios for propulsion on level surfaces.

The individual data points plotted on Figure 1-3 along with the size of the Standard Errors of Estimate for the polynomials in Table 2 indicate considerable variability among the responses of the subjects. Examination of Figures 1-3 reveals a range of efficiency from 4.5% for one subject for the 1:1 gear ratio at 2.3 Km/Hr (10W) in Figure 2 to a high of 19.9 for a different subject at the 2:1 gear ratio at 9.3 Km/Hr (41W) in Figure 3. Although the points are not connected to show the relationship of conditions for individuals in Fig. 1-3, the raw data show different shapes (slopes) of the individual data curves. This may be accepted as evidence that individual differences exert a substantial influence on the conditions which are consistent with optimum efficiency. When considered in this manner it becomes apparent that the variability induced by subject variables such as strength and segment dimensions must be considered in order to determine gear ratio consistent with optimum efficiency.

Such factors as arm length, sitting height and strength may, therefore, be hypothesized as critical variables in the optimization of efficiency on the basis of this data.

The average efficiency for propelling a wheelchair with 0.25M levels over level ground at 4.7 Km/Hr may be found in Figure 1 to be about 11%. This condition is comparable to the mechanical advantage for typical rim propelled wheelchairs for which the efficiency has been reported to be in a range of 4-6% (1,2,3). From this comparison it is apparent that lever propulsion is considerable more efficient than hand-rim propulsion for typical wheelchair usage.

REFERENCES

1. Hildebrandt, G., et al: Arch. Phys. Med. Reh. 51: 131-136, 1970.
2. Stoboy, H., et al: Paraplegia, 8: 223-230,1971.
3. Brattgard, S.O., et al: Scand. J. Rehab. Med.2: 143, 1970.
4. Voight, E.C., et al: Scand. J. Rehab. Med. 1: 101-106, 1969.
5. Brubaker, C.E., et al: Med. Sci. Sport 11(1): 76, 1979.
6. Brubaker, C.E., et al: Wheelchair III, V.A. Hosp., LaJolla, 1983.
7. Zwiren, L., et al: Med. Sci. Sport, 7: 94-98, 1975.
8. Engel, P., et al: Proc. Roy Soc. Med. 67: 409-413, 1974.
9. Engel, P., et al: Rehabilitation, 15: 217-228, 1976.

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C.E. Brubaker, UVa REC, PO Box 3368,
Charlottesville, Virginia 22903

THE DEVELOPMENT OF WHEELCHAIR STANDARDS

L. R. Phillips, P. W. Axelson, D. A. Hobson, S. R. McFarland

ABSTRACT

A recent development in the rehabilitation engineering field has been a concerted effort to develop voluntary standards for manual and powered wheelchairs. This development has occurred in response to several factors, including international cooperation on the development of wheelchair standards, U.S. government interest in the development of domestic standards, and consumer advocacy for the development of such standards.

This paper traces the history of both international and domestic wheelchair standards efforts. It describes the significant role that RESNA is playing in the development of wheelchair standards through the leadership role being provided by the RESNA Subcommittee on Wheelchair Standards Development. RESNA currently serves as the official U.S. representative to the International Standards Organization's (ISO) Wheelchair Standards Subcommittee. The RESNA Subcommittee also is developing voluntary U.S. standards for wheelchairs in cooperation with the Veterans Administration and the Food and Drug Administration.

The RESNA Subcommittee has established an ambitious work schedule for itself and is anticipating the completion of voluntary domestic standards for both manual and powered chairs by the close of 1986.

BACKGROUND

The development of wheelchair standards in the United States can be attributed in part to the Veterans Administration's efforts during the past five years to issue purchasing standards for wheelchairs for veterans. In 1977, the VA published performance standards for manually powered wheelchairs. Standards for powered wheelchairs were published in December, 1981. The purpose of these documents was to indicate the minimal requirements of wheelchairs purchased by the Veterans Administration for veterans who were eligible for VA-supplied wheelchairs.

It is important to note that the VA Standards never were intended for use as an American National Standard for wheelchairs. The VA draft standards were developed to meet the needs of the adult male who requires a wheelchair primarily as a result of trauma.

The Food and Drug Administration (FDA) is charged with the responsibility of establishing standards for medical devices, including wheelchairs. Under the Reagan Administration, FDA has been encouraged to develop voluntary standards rather than mandatory standards for as many devices as possible. The FDA considers wheelchairs to be an appropriate device for voluntary standards.

A concurrent effort for the development of wheelchair standards has been the International Standards Organization's (ISO) convening of a Wheelchair Standards Committee. ISO is a non-profit international organization that is dedicated to the development of voluntary standards for products and devices used throughout the world. Based in Geneva, the ISO created its Wheelchair Standards Committee (ISO TC 172/SC1) to develop consensus standards for all countries interested in participating. To date, the following countries have participated in the work of the Wheelchair Standards Committee: Sweden, France, Denmark, Holland, The United Kingdom, West Germany, Canada, Japan, and the United States.

When the United States began its participation on the ISO Wheelchair Standards Committee, the American National Standards Institute (ANSI) designated the Health Industries Manufacturing Association (HIMA) as the official U.S. representative. HIMA organized a Technical Advisory Group (TAG) and provided administrative support to the ISO wheelchair standards effort. The TAG committee chairperson at that time was Keith Rodaway of Everest and Jennings.

In the fall of 1981, RESNA organized a Wheelchair Committee under the direction of Dr. Doris Rouse, Chairperson. Dr. Rouse appointed Douglas Hobson to chair a Wheelchair Standards Subcommittee, the purpose of which was to develop recommendations for domestic wheelchair standards. Following an initial organizational period, the Subcommittee convened for its first meeting in March, 1982.

The Subcommittee established two initial priorities: development of a classification system for wheelchairs; and development of draft standards for powered wheelchairs.

These two priorities were identified for a number of reasons. At the present time, for example, no universal classification system exists for wheelchairs. This means that the same criteria are being applied to manual chairs for hospital use as are applied to manual chairs for independent user use. The same problem occurs with respect to powered wheelchairs. The committee felt that establishment of a classification system was essential, therefore, before any standards for wheelchairs were developed.

The Subcommittee also tentatively decided at that time to concentrate its efforts upon powered wheelchairs, since the Canadian Standards Association had been working for some time upon the development of standards for manual wheelchairs. It was hoped that the Subcommittee thus could dovetail its standards efforts with those of the Canadians.

The original goals of the Subcommittee were changed significantly during the first year of its existence due to changing needs and priorities. The RESNA Subcommittee was asked by the ISO TAG committee to assist them in re-writing a document on manual wheelchair standards for the November, 1982 meeting of ISO TC 172/SC1. The RESNA subcommittee complied with their request, and met several times to work on the document in question, N-3. Much of the groundwork for the revisions was laid at a June meeting in Charlottesville, Virginia, with additional work being accomplished at a Subcommittee meeting in August.

During the same period of time, chairmanship of the ISO TAG committee was transferred from Keith Rodaway of Everest and Jennings to Dr. Colin McLaurin of the University of Virginia.

Many of the RESNA subcommittee members also are members of the ISO TAG committee. Since the RESNA subcommittee was so successful in its efforts to revise the N-3 document, it was decided in late 1982 to transfer ISO representation from HIMA to RESNA. At a January 21, 1983 meeting in Washington, D.C., the RESNA Subcommittee indicated its support for the transfer of responsibility.

SUBCOMMITTEE ACCOMPLISHMENTS

The RESNA Wheelchair Standards Subcommittee has been a productive committee from its organizational meeting in March, 1982. From an administrative standpoint, it has been able to attract admirable levels of funding for its first year in operation. For example, the Veterans Administration provided travel funding for many Subcommittee members to attend the March, 1982 meeting, which was held in conjunction with the VA-sponsored Wheelchair III. In addition, the VA provided meeting space at the VA Medical Center in La Jolla, California.

The Paralyzed Veterans of America also has made significant contributions to the Subcommittees. All Subcommittee administrative functions including budget management, are coordinated through PVA's Research Department in Washington, D.C. PVA's Technology and Research Foundation is the largest financial supporter to date, having given RESNA $8,000 as start-up funds for the Subcommittee.

Three wheelchair manufacturers - Everest and Jennings, Invacare, and Theradyne - have made donations to the Subcommittee. Everest and Jennings and Invacare each gave $2525 for the first year of operation, with pledges of $2525 for each of the next four years as well. Theradyne donated $500 to the Subcommittee for its work on wheelchair standards.

The sound financial and administrative basis of the Subcommittee has been reflected in solid programmatic accomplishments. Of the greatest significance is the preparation of the ISO document, N-3, on standards for manual wheelchairs. The Subcommittee proposed and performed actual testing of many of the performance criteria developed for the draft international standards. The United States was complimented at the November, 1982 meeting of the ISO Committee for its important contributions to the N-3 document.

The RESNA Subcommittee recently began to develop priorities of test standards for wheelchairs. At its March, 1983 meeting, the Subcommittee developed comprehensive listings of desirable safety and design features for both manual and powered wheelchairs. These comprehensive listings then were prioritized, and will be used as the basis upon which domestic wheelchair standards will be developed.

Both the RESNA and ISO TAG Committees are characterized by their inclusion of a good balance of interested parties on their membership rolls. Manufacturing interests, federal agency officials, rehabilitation engineers, and consumers participate equally in the committee work and in the development of consensus standards.

The pace of work for the ISO standards efforts cannot be controlled, due to the need to accomodate the interests of all countries participating. However, the RESNA Subcommittee is anticipating the completion of voluntary domestic standards by the fall of 1986. This will culminate an intensive five year standards effort on the part of RESNA.

Short-term goals are to secure funding to support the work of the Subcommittee for the remaining four years of standards development work. While the corporate pledges will serve as a basis for continuation of the committee, they do not cover all of the expenses incurred during the four domestic meetings and two international meetings that generally occur in a given year. Additional funding sources are being explored to address this problem.

From a technical standpoint, short-term goals include evaluation of proposed test methods and drafting of additional test methods for the priority areas outlined at the January, 1983 meeting.

SIGNIFICANCE

The RESNA Subcommittee is representative of the kind of progress that can be made when consumers, manufacturers, engineers, and federal agency representatives cooperate from the onset of a project to develop a mutually acceptable concept or program. A side benefit of this aspect is the increased communication that occurs among various segments of the population that ordinarily would not take place. A second major area of significance is that this project presumably will lead to a definite end product - wheelchair standards that can be used by industry to make a product that will be acceptable to purchasers and to regulators. Finally, it is significant that RESNA has taken the lead in developing these standards, since RESNA is one organization which truly can represent all interested parties.

ACKNOWLEDGEMENTS

The Subcommittee could not accomplish its goals without the financial support that has been provided by: the Paralyzed Veterans of America's Technology and Research Foundation; Everest and Jennings; Invacare; Theradyne; and the Veteran's Administration. The authors of this paper also would like to acknowledge the work that has been done by: the Subcommittee members; Wheelchair Committee Chairperson Doris Rouse; PVA Research Secretary Marcie Sipe; and A. Bennett Wilson, the Subcommittee's Technical Secretary.

L. R. Phillips
Paralyzed Veterans of America
801 Eighteenth Street, NW
Washington, DC 20006

5.8

PVA HINGE FOR POWERED RECLINING WHEELCHAIRS

C. Gerald Warren, MPA   Thomas C. Stone, PE   Larry A. Sims

INTRODUCTION

People who are severely paralyzed or otherwise disabled to the point of being unable to move or control the positioning of their trunk often use powered reclining wheelchairs. This recline function is important to these people because it allows them to independently redistribute and/or decrease pressure on weight-bearing surfaces and to rest residual trunk and respiratory musculature. Use of this equipment tends to decrease the likelihood of tissue damage and fatigue. People using powered reclining wheelchairs can also be observed re-orienting themselves with the recliner during conversations, allowing them to use some degree of body language.

A frequent complaint of users of this equipment is that with repeated recline their bodies often are shifted out of the normal stable position which causes loss of sitting balance. Repeated recline also can cause wrinkling or bunching of the clothing which in itself can cause pressure concentrations. To correct these conditions very often the user must ask for assistance in repositioning and this limits his/her functional independence.

When a wheelchair with a standard hinge is reclined the person tends to slide down the back and during elevation of the chair back, shear forces between the person and the chair often prevent restoration of the original position. This occurs because the location of the pivot points of the chair differ from the effective axis of rotation of the person's body during recline. The type of motion which occurs is shown schematically in figure 1.

A study of methods to reduce and/or compensate for this downward sliding motion of the body was performed (ref. 1). Several mechanisms were evaluated: the use of a sliding chair back which followed the person's back by sliding up and down the side rails of the frame of the chair back, the use of a sliding seat which moved the wheelchair seat rearward approximately 4.8 cm at full recline, and a four-bar linkage which caused the chair back to follow the path of the person's body during recline. The comparisons were performed on a sample of eight quadriplegic individuals, the effectiveness of the solution was determined by measuring the amount of displacement which occurred between the person and the chair frame as they went through a 10 to 80 degree recline cycle. The conclusions of that study were that the sliding back mechanism required excessive structural rigidity in the back to maintain the alignment necessary for it to operate. Secondly, the sliding seat when used with the ROHO cushion only reduced the maximum average displacement of the person in the chair from 11.0 to 9.5 cm. Finally, when a four-bar linkage, designed to follow the path of the body, was used, the average displacement was reduced from 11.0 to 0.9 cm.

The four-bar linkage was suitable for incorporation into the redesign of the wheelchair; however, there is an apparent need for this type of equipment to be retrofitted to existing wheelchair frames if the problem was to be addressed in a timely fashion. Therefore an application was made to the Paralyzed Veterans of America, Technology and Research Foundation, to fund a project to design a hinge mechanism that could be used in a

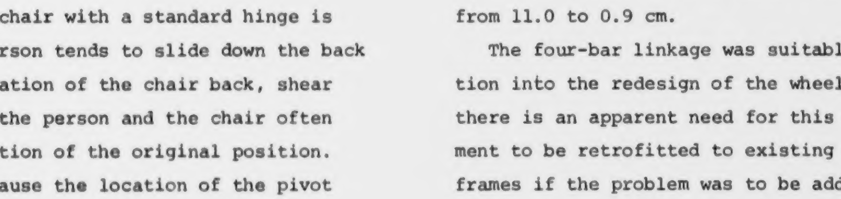

Figure 1. Schematic representation of displacement during recline.

retrofit system. This could be installed on power reclining wheelchairs currently owned by individuals needing to solve this problem and could be included as an option in the delivery of powered reclining wheelchairs which use the standard tubular frame design.

METHOD

With the data in hand which described the path of a person's body during the recline cycle, the task was to design a hinging mechanism which would replicate the desired pathway, fit the space constraints, and easily attach to the existing frame of reclining wheelchairs. Other standard criteria, such as safety, stability, and in particular cost of manufacture, were major considerations in the development of the design.

From design study of several alternative methods, a multiple link system was selected which mounted on the existing attachment points of the wheelchair frame (Everest & Jennings 3P-47 frame). It consisted of an actuator link which attaches to the linear actuator beneath the chair (figure 2). The motion of the actuator acts through a series of seven links to drive the back tubes of the chair through the desired path. The system can be generically described as a double scissors link with four-bar termination at each end. The upper termination which inserted into the back tube of the chair was the only part of the design which required structural alteration. The tube needed to be shortened by approximately 3-1/2 inches. A boot to cover the linkage mechanism was designed to protect clothing and body segments from becoming engaged in the mechanism.

A complete prototype of the hinging mechanism was produced of mild steel with all formings and small parts generated by hand. The covering boot design was approximated by using wire-formed plastic tube. The device was installed on a powered reclining wheelchair to determine how well it accomplished the design objectives and to determine at what points gross wear or gross yielding might occur. The mechanism performed with a maximum error of 6 mm from

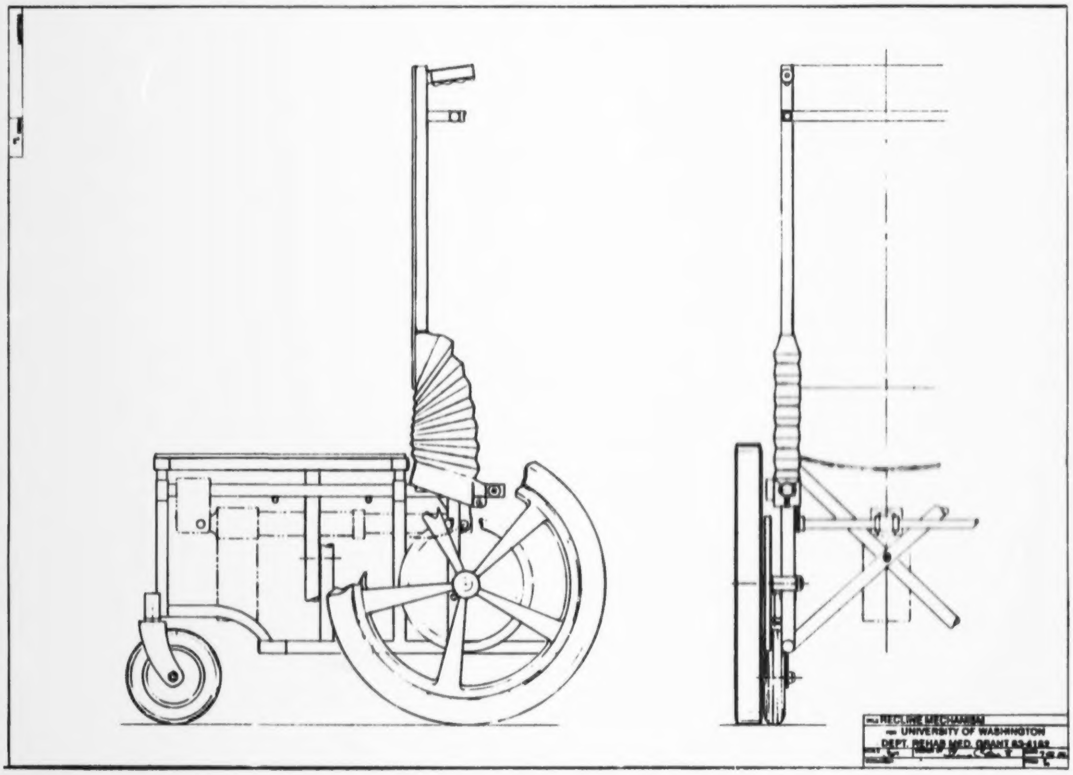

Figure 2. Installation of PVA hinge on reclining wheelchair frame.

the designated rotational curve. The function of the hinging mechanism was smooth and stable, the prototype link stresses were carried even with the mild steel; however, it is definitely recommended that these be made from a higher yield material to avoid damage from accidental or improper loading. A similar consideration was made for the pin pivots and the bushing, which in the prototype were drill rod and mild steel, respectively.

TECHNOLOGY TRANSFER TO INDUSTRY

With complete documentation and prototype available, the next task was to transfer this technology to a manufacturer. The objective was to seek out a manufacturer who could incorporate the hinging mechanism into a nationally distributed product line. After several demonstrations and inquiries, Abbey Medical declared an intent to pursue marketing evaluation and production design. Through the use of an invention disclosure agreement, documentation and prototypes were transferred to the Abbey Medical Corporation Research and Development facilities to determine the production feasibility and the viability of the product in their line of wheelchair assemblies and/or accessories. After determining that there was indeed a market for such a mechanism, the primary concern was production cost and the ultimate price of the mechanism in the marketplace. Since low cost of parts and fabrication was a major element of original design criteria, it was found that the production cost of the hinge when incorporated into a reclining system was well within the marketable range. At that point the manufacturer entered into the production prototype phase and the negotiation of a licensing agreement began. A licensing agreement was negotiated by the Washington Research Foundation, a nonprofit corporation who act as the technology transfer agent for the University of Washington.

As is the case with most products developed in the area of rehabilitation, the volume of sales is not as high as generally anticipated in other forms of product development. It was therefore agreed that a one-time fee would be negotiated based on the anticipated general worth of the invention. This is, of course, a difficult number to establish and, as is often the case, the inventors' primary objective was to make the technology available to the disabled persons who need it. Because of the paucity of data available from either marketing or sales research on rehabilitation equipment, neither party in such licensing agreements usually has a good basis for negotiating; therefore, a key element in technology transfer in this field remains the element of "good faith bargaining."

CONCLUSIONS

The product development of the PVA hinge was the result of several factors. It emanated from: some relatively basic research which accurately described the problem and mechanism of displacement experienced by quadriplegic persons using powered reclining wheelchairs; secondly, the design and demonstration of a solution, i.e., the four-bar linkage which would cause the chair back to follow the path of the individual during recline; thirdly, the funding by the Paralyzed Veterans of America of a product development phase of the project which brought the concept to a viable position for technology transfer. The key component to this accomplishment was establishing the proper design criteria. The final phase is the negotiation of the transfer of the technology to a manufacturer who has the appropriate resources and marketing capability for the product.

ACKNOWLEDGMENTS

1. A special thanks to the board of the Technology and Research Foundation of the Paralyzed Veterans of America for granting the funds to accomplish the critical phase of this product development.

2. This project was conducted at the Department of Rehabilitation Medicine, University of Washington.

REFERENCE

Warren, C. Gerald, MPA; Ko, Michael, MS; Smith, Craig, BS; Imre, John V., MA; Reducing Back Displacement in the Powered Reclining Wheelchair, Archives of Physical Medicine Rehabilitation, Vol 63 (Sept 1982), pp 447-449.

C. Gerald Warren, Clinical Associate Professor
Department of Rehabilitation Medicine
University of Washington
President of C. Gerald Warren and Associates
4825 Stanford Ave, NE
Seattle, WA 98103

Thomas C. Stone
Professional Engineer
726-A North 43rd
Seattle, WA 98103

Larry A. Sims, Director
Research & Product Dev.
Abbey Medical
3216 W. El Segundo Blvd.
Hawthorne, CA 90250

A Vehicle to Permit Locomotion Via Paralyzed Leg Muscles

5.9

R.M. Glaser, J.A. Gruner, S.D. Feinberg, S.R. Collins, and J.S. Petrofsky.
Dept. of Physiology, Wright State University School of Medicine, Dayton,
OH 45435, and Rehabilitation Institute of Ohio, Miami Valley Hospital,
Dayton, OH 45409.

ABSTRACT

Functional electrical stimulation has been used to restore some degree of controllable movement to paralyzed muscle. The purpose of this study was to demonstrate the feasibility of using electrically stimulated paralyzed leg muscles to propel a wheelchair-type vehicle. For this, a conventional manual wheelchair was modified by the addition of a drive system which permits forward propulsion by reciprocating movements of the legs. A battery powered electrical stimulator using surface electrodes over the quadriceps muscles controls the strength, duration and frequency of contractions. This vehicle has been successfully operated by paraplegic and quadriplegic test subjects. Advantages of using paralyzed leg muscles for locomotion may include improved: locomotive capability, circulation in the lower extremities; cardiovascular and respiratory fitness; strength and size of the exercised muscles and bones; and, self-image.

INTRODUCTION

Since skeletal muscle paralysis is oftentimes considered permanent, a major philosophy in the rehabilitation of paralyzed individuals is to make compensatory use of functional muscles. Thus, in cases of lower limb paralysis, wheelchairs which are propelled by the upper body musculature are frequently prescribed. The conventional handrim operated wheelchair, however, has been reported to be inefficient and stressful to the muscular, cardiovascular and respiratory systems (1,2,3,4). These stresses could discourage locomotion, and the sedentary lifestyle of many wheelchair-dependent individuals can contribute to a further loss of physical fitness (5,6).

To improve the rehabilitation of paralyzed individuals, recent research has been aimed at restoring some degree of function to paralyzed muscles via electrical stimuation (7). Functional electrical stimulation (FES) has been used to exercise paralyzed muscles (8,9,10) and permit them to perform rudimentary tasks to assist in ambulation (11,12,13). Ultimately, use of paralyzed muscles for free walking should be possible if many technological and physiological problems could be solved relating to: fitness of muscles, bones and joints; fine control and coordination of multiple muscles; obtaining necessary motor (efferent) and sensory (afferent) signals for regulating activity and maintaining posture and equilibrium; and miniaturization and implantation of required electronic circuits.

Because of the extensive problems involved in using paralyzed muscles for free walking, it seems reasonable to develop an *intermediate* system in which electrically stimulated paralyzed muscles could be used for locomotion--in a sitting positon. It was therefore the purpose of this project to develop a wheelchair-type vehicle which could be propelled via simple movements of electrically stimulated paralyzed legs. This leg propelled vehicle (LPV) system could potentially alleviate many of the problems associated with conventional arm propelled wheelchairs, while helping to develop and maintain fitness of the paralyzed legs.

METHODS

Leg Propelled Vehicle

The LPV during operation is illustrated in Fig. 1. To facilitate constructon of the LPV, an Everest and Jennings model Universal wheelchair was modified. This permitted use of the original frame, hammock seat, large handrim operated drive wheels, and the swivel casters. The primary additions to the wheelchair were two moveable footplates which were coupled to the drive wheels via ratchet-type transmissions. With forward extension of the legs, the pawls of the ratchet systems engage causing forward rotation of the drive wheels. With backward movement of the legs, the pawls of the ratchet systems disengage permitting the drive wheels (and vehicle) to coast forward. Since a separate ratchet transmission is used for each drive wheel, forward locomotion can be accomplished with synchronous or asynchronous reciprocating movements of the legs. Large radius steering can be accomplished by consecutive movements of a single leg.

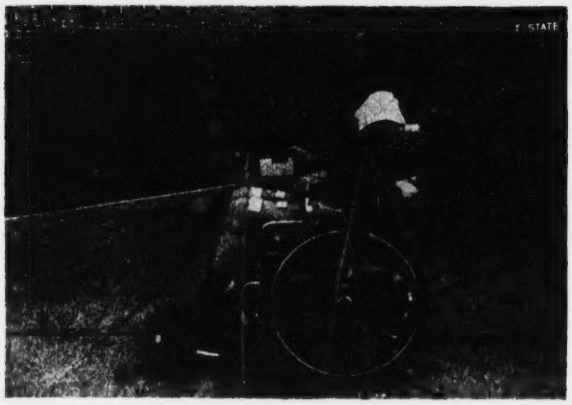

Fig. 1. Leg propelled vehicle in operation.

Fig. 2 provides a close-up view of a moveable footplate (A) which is coupled to a drive wheel (B) via a ratchet transmission (C). The footplate slides along two rods by way of linear ball bearings. This linear motion of the footplate operates a series of linkages, pivotally mounted levers, and a pawl. Thus, forward movement of the footplate engages the pawl with the drive gear, and the circular movement of the pawl mounting lever, which pivots on the axle, causes the drive gear to rotate in a forward direction. Any backward movement of the footplate completely disengages the pawl from the drive gear. From Figures 1 and 2 it can also be noticed that the LPV is essentially a three-wheeled system with the weight distributed between the two drive wheels and a centered front swivel caster. The swivel caster in the rear usually remains about 2 cm above the ground, and prevents backward tipping with forward acceleration.

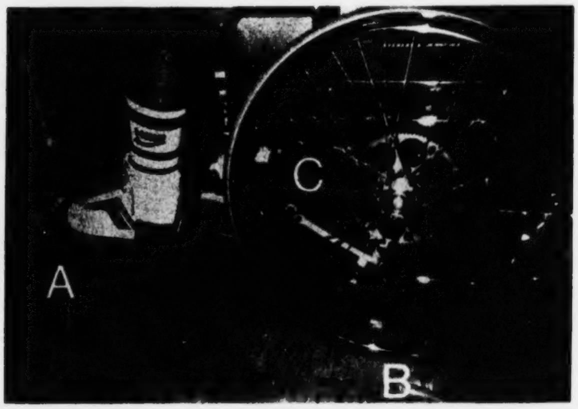

Fig. 2. Close-up view of ratchet drive system. A-moveable footplate; B-drive wheel; C-ratchet transmission.

Electrical Stimulator System

A two channel, battery powered electrical stimulator, which mounts upon the LPV (Fig. 1), was constructed. Three skin surface electrodes (3M Company) are provided at each stimulator channel output--an anode (common) and two cathodes. The anode is placed closest to the knee. The cathodes are placed over separate motor points of the quadriceps muscle group, which elicit desired movements at the lowest threshold voltage levels. Frequency of muscle stimulation is set at 60 Hz. However, voltage application to the pair of cathode electrodes sequences back and forth. Therefore, individual muscle fibers are being stimulated at one-half of this rate which may delay the onset of fatigue (14). Current output is manually adjustable from 0-100 milliamperes, at a maximal peak potential of 65 volts. Pulse width is manually adjustable from 10-500 microseconds.

Manual operation of this stimulator is accomplished by three push button switches (right leg, left leg, or both legs together). This provides a choice of asynchronous or synchronous locomotive patterns. An astable flip-flop circuit is built into the stimulator for automatic operation. In this mode, the rate at which the legs are stimulated is fully adjustable.

To protect against over-stimulation of the muscles, which could potentially cause damage to the muscles, bones and joints of the legs, limit switches cut off electrical stimulation prior to the footplates reaching the end of their forward range of travel. In addition, knee and/or ankle supports are worn by subjects when appropriate.

Subjects

College-age paraplegic and quadriplegic volunteers have been used to evaluate operation of the LPV. These subjects were relatively free of lower motoneuron damage, and did not suffer from cardiovascular, pulmonary or other impairments which would contraindicate participation. This project has been approved by the Human Subjects Research Committees of Wright State University and Miami Valley Hospital.

RESULTS AND DISCUSSION

A prerequisite for successful FES is that motor units are intact (7). If there is extensive denervation of the muscles, electrical stimulation via skin surface electrodes would not be feasible because of the high current levels required to elicit contractions. Denervation of the quadriceps muscles tends to occur with injuries to the lumbar region of the spinal cord. Therefore, the LPV could potentially be used by the majority of spinal cord injured patients since they have higher level injuries. Most of these individuals will not perceive the electrical impulses due to disruptions of sensory pathways ascending to the brain.

For a 70 kg individual operating the LPV on a smooth, level surface, about 1.5 kg of force is required to move the footplates forward. Essentially all of the spinal cord injured patients that we have evaluated during electrically induced exercise of the quadriceps muscles (more than 25) can easily generate this force--even if they have been paralyzed for as long as 10 years. Recent experiments in our laboratories indicate that conditioning programs for these muscles which incorporate progressive intensity and duration exercise result in marked increases in strength and endurance. As expected, when the LPV requires greater force to operate (or when muscles fatigue during prolonged operaton) higher stimulation currents are needed to recruit additional muscle fibers in an attempt to accomplish the task.

The LPV as described was designed to test the feasibility of using paralyzed leg muscles for locomotion. Initial testing with two quadriplegic and four paraplegic subjects clearly indicates that this concept of restoring movement to paralyzed muscles for the purpose of propelling a vehicle is achievable, and may be desirable considering the potential beneficial effects. In addition to improving locomotive capability, use of the LPV may also: improve circulation of blood in the lower extremities which could reduce the occurrence of thrombus formations and decubitus ulcers; improve cardiovascular and respiratory fitness; increase the size and strength of the exercising muscles and bones which could improve appearance and decrease the risk of injury; and improve self-image.

The present design of the LPV does not permit small radius steering, reverse operation, or braking when using the legs for propulsion. For these maneuvers, the handrims must be used. Future LPV designs should provide for greater maneuverability. It is conceivable that a microprocessor based stimulator system (14), with a joystick type controller and feedback sensors on the drive mechanism, could be incorporated to enable a greater degree of muscle control for more precise locomotive tasks. Such a system could automatically compensate for fatiguing muscle fibers, and changes in the terrain.

Another advantage of retaining the handrim system on the LPV is that both the arms and legs may be used to operate this vehicle simultaneously. Such propulsion could reduce the stresses of locomotion because greater muscle mass could be incorporated than when using the arms or legs alone. This may also be helpful in maintaining total body fitness.

The LPV may be beneficial for patients who have voluntary leg function, but cannot walk effectively because of weakness, lack of coordination, or orthopedic or other medical problems (15). Many of these non-paralyzed individuals propel conventional wheelchairs with their arms or legs (by removing the footrests and either pushing or pulling the wheelchair along the floor with their feet). To determine any advantages of using the LPV for such individuals, we tested several geriatric (up to 95 years old) nursing home patients. Most of these individuals found the LPV to be easier to propel than their usual wheelchairs. We are, however, unaware of commercially available wheelchair-type vehicles designed for leg (or arm and leg) propulsion.

In conclusion, the concept of using electrically stimulated leg muscles for propulsion of a specially constructed vehicle appears to be quite feasible. In addition to greater locomotive capability, many health benefits may be derived from the exercise. The LPV may even substitute, in some instances, for motorized wheelchairs. In these cases, paralyzed muscles would take the place of the motor and metabolism would provide the energy.

ACKNOWLEDGEMENTS

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REFERENCES

1. Hildebrandt G, Voigt E-D, Bahn D, Berendes B, Kröger J: Energy costs of propelling wheelchair at various speeds: Cardiac response and effect on steering accuracy. *Arch Phys Med Rehabil* 51:131136, 1970.

2. Wolfe GA, Waters R, Hislop HJ: Influence of floor surface on the energy cost of wheelchair propulsion. *Phys Ther* 57:1022-1027, 1977.

3. Glaser RM, Laubach LL, Sawka MN, Suryaprasad AG: Exercise stress, fitness evaluation and training of wheelchair users. In: *Proceedings - International Conference on Lifestyle and Health, 1978: Optimal Health and Fitness for People with Physical Disabilities* (eds AS Leon, GJ Amundson) University of Minnesota Press, Minneapolis, MN, pp. 167-194, 1979.

4. Glaser RM, Sawka MN, Young RE, Suryaprasad AG: Applied physiology for wheelchair design. *J Appl Physiol: Respirat Environ Exercise Physiol* 48:41-44, 1980.

5. Glaser RM, Sawka MN, Durbin RJ, Foley DM, Suryaprasad AG: Exercise program for wheelchair activity. *Am J Phys Med* 60:67-75, 1981.

6. Voigt E-D, Bahn D: Metabolism and pulse rate in physically handicapped when propelling a wheelchair up an incline. *Scand J Rehab Med* 1:101-106, 1969.

7. Mortimer JT: Motor Prostheses. In: *Handbook of Physiology - The Nervous System II* (eds JM Brookhart, VB Mountcastle, VB Brooks, SR Geiger) Am Physiol Soc, Bethesda, MD, pp. 155-187, 1981.

8. Peckham PH, Mortimer JT, Marsolais EB: Alteration in the force and fatigability of skeletal muscle in quadriplegic humans following exercise induced by chronic electrical stimulation. *Clin Orthop Rel Res* 114:326-334, 1976.

9. Glaser RM, Petrofsky JS, Gruner JA, Green BA: Isometric strength and endurance of electrically stimulated leg muscles of quadriplegics. (abst) *Physiologist* 25:253, 1982.

10. Petrofsky, JS, Glaser RM, Phillips CA, Gruner JA: The effects of electrically induced bicycle ergometer exercise on blood pressure and heart reate. (abst) *Physiologist* 25:253, 1982.

11. Waters R, McNeal DR, Perry J: Experimental correction of footdrop by electrical stimulation of the peroneal nerve. *J Bone Joint Surg* 57:1047-1054, 1975.

12. Brandell BR: Development of a universal control unit for functional electrical stimulation (FES). *Am J Phys Med* 61:279-301, 1982.

13. Kralj A, Vodovnik L: Functional electrical stimulation of the extremities: Part I. *J Med Eng Technol* 1:12-15, 1977.

14. Petrofsky JS: Control of the recruitment and firing frequencies of motor units in electrically stimulated muscles in the cat. *Med Biol Eng Comput* 16:302-308, 1978.

15. Garcia EE, Glaser RM, Fichtenbaum BM, Ruchman TJ, Petrofsky JS: Stress analysis for operating a multipropulsion mode wheelchair (abst) *Physiologist* 25:201, 1982.

Mailing Address: Dr. Roger M. Glaser,
Department of Physiology, Wright State
University School of Medicine, Dayton, Ohio 45435

5.10 NEW CONTROL TECHNIQUES FOR WHEELCHAIRS

G. Schmeisser, M.D.
The Johns Hopkins Medical Institutions
W. Seamone
The Johns Hopkins University Applied Physics Laboratory

ABSTRACT

Handicapped persons who require the use of an electric wheelchair yet who possess normal hand control usually find conventional joystick controllers quite adequate for their mobility requirements. However, individuals with poor hand control, or high spinal cord injured persons whose only available motion is head or chin motion, have considerable difficulty in finding an adequate solution to their needs.

This paper will describe the results of development at the Applied Physics Laboratory of new controllers for wheelchairs, and the use of closed loop velocity control with filtering to minimize effects of erratic motion. Experimental application of a microprocessor to wheelchair control will also be discussed. Results of evaluation of these experimental wheelchair controllers by quadriplegic volunteers will be presented.

BACKGROUND

A research program sponsored by the Veterans Administration has been underway for the past eight years at the Applied Physics Laboratory for the purpose of investigating the merits of a robotic arm/work table system for high spinal cord injured persons.[1] The primary effort of this program has been directed at designing, fabricating, and evaluating the robotic arm and its related special tools.

An important component of the overall system is a device which is a control input interface for both the robotic arm and the electric wheelchair of the quadriplegic user. The scope of this paper is limited to the role of this device as a wheelchair controller. Significant design features of several models and the clinical characteristics and experiences of high level quadriplegics who have used them are presented.

Chin Controller

The traditional VA wheelchair controller for a person with residual voluntary motion limited to the head and neck is box-shaped, has a small joystick, and is mounted on a bracket in front of the operator's face where he can move the joystick with his chin.[2,3] Moving the chin up and forward controls forward speed. Moving it left or right controls turning, and moving the controller down and backward controls reverse speed. Although this controller provides reasonable control for certain individuals, it is sensitive to rough terrain and is obstructive in front of the face.

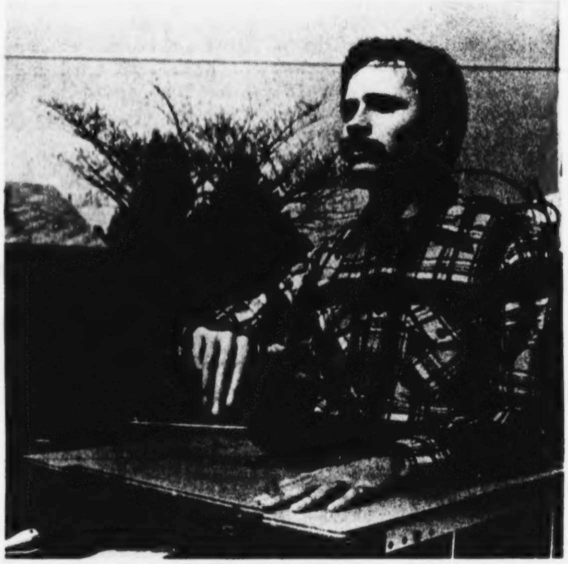

Fig. 1 APL Chin Controller Shown in Wheelchair Driving Position

Two important design goals in the design of the APL chin controller[4] were minimal apparatus in front of the face, and improved wheelchair controllability downhill and over rough terrain. The first goal was achieved by locating the controller's two-axis sensing mechanism on the back of the wheelchair behind the base of the user's head. An inconspicuous tubular extension curves around one side of the neck and terminates just below and in front of the chin. This design concept is shown in Figure 1. Downward motions of the chin depress this lever, therby controlling wheelchair velocity. Lateral movements of the lever provide lateral control. When the user has no need for mobility control, he can easily push the controller aside with his chin, thereby clearing the area in front of his face. Whenever he desires, the quadriplegic can retrieve the controller by chin motion alone. The excellent cosmetic appearance of this controller is shown in Figure 1 in its normal driving position.

Early models of the two-axis sensor incorporated potentiometers for sensing, whereas later models utilized optical angular sensors. The potentiometers require less electronic circuitry but can deteriorate due to wear. The optical transducers, on the other hand, are less expensive but require critical mechanical alignment. Two different models of the sensor, one fitted with potentiometers, the other with optical transducers, were interfaced with an Everest and Jennings (E&J) Model 3P Electric Wheelchair. The arrangement of the mechanical and electronic components on the back of the wheelchair is shown in Figure 2. A total of seven units were fabricated and evaluated by quadriplegic volunteers who used this system full-time over periods ranging from a few months to over four years. Significant clinical characteristics and relevant experiences of individuals who used this equipment during this period are presented below:

Evaluation Results

- C. R., a 32-year-old veteran with spinal stenosis, resulting in quadriplegia ten years ago, is living in a State hospital and commutes daily by van to a community college. He received his test wheelchair and control system in early January 1980. He has been active in it all day and evening. C. R. used the wheelchair controller for approximately six weeks, in combination with the APL robotic/arm work table system, in an evaluation of its patient self-feeding potential. After testing the wheelchair alone for over three years, he continues to prefer this controller to his conventional joystick box-type VAPC controller.

- M. S., a 25-year-old veteran injured five years ago, lives in a suburban nursing home. The test control system was attached to his existing wheelchair in early April 1980. With the system M. S. continues to be actively mobile in his wheelchair for at least eight hours per day. His wheelchair provides the mobility to attend classes.

- B. J. is a 21-year-old injured five years ago. He received his test wheelchair in January 1979. Use of the wheelchair made it possible for him to complete high school and to continue his college education. With this wheelchair, he has pursued his college education both in Denver, Colorado and in Regensburg, Germany. He noted that despite the head bobbing caused by the cobblestone streets in Regensburg, he was able to drive where he wanted to go Four years after receiving the unit, he continues to praise the chin controller as invaluable in his day-to-day living.

- D. W. is a 35-year-old man injured five years ago. He is a quadriplegic with no significant voluntary muscle power below his shoulders. He was originally provided with an electric wheelchair with APL chin controller in November 1980. He had previously rejected use of a joystick box-type controller due to its obstructiveness. He is well pleased with the cosmesis and performance of his APL controller. His home is located on hilly terrain and he uses this wheelchair and controller for outdoor mobility primarily in the immediate vicinity of his home. He has had no mechanical or electrical problems for the last year and a half.

- J. C. is a 45-year-old injured 12 years ago. He currently lives in a rural nursing home. He received two different early models of the test wheelchair and control system about five years ago. He is active in his wheelchair for only a few hours at a time on an infrequent basis.

With the exception of J. C., who spends substantially more time in bed than the others, all of these quadriplegics have been using the APL chin controller on a daily basis, are enthusiastic about its performance.

Reliability of all units has been good, with a failure rate of approximately one per six months of use. In order to further minimize costs and improve reliability, a newer model has been constructed with a sensor mechanism which can take much more physical abuse than previous models. Slip joints have been provided in the mechanism which enable user realignment if the device is inadvertently misaligned by an attendant. This controller has been tested in the Laboratory and may be incorporated in a clinical test model at some future date.

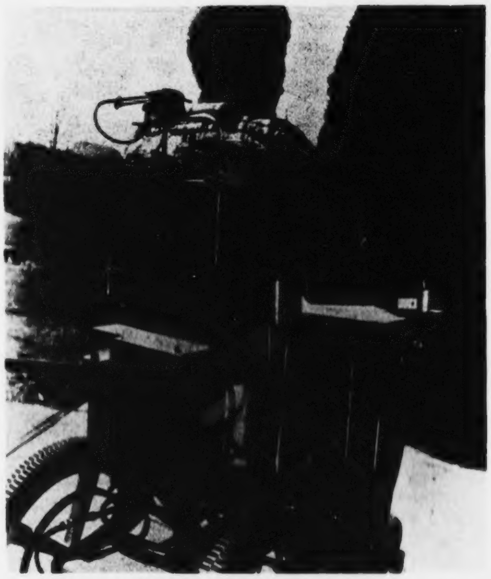

Fig. 2 Chin Controller Components Mounted on Rear of Wheelchair

Closed-Loop Velocity Control

The second important feature of the APL chin controller is its closed-loop velocity control. One of the advantages of this feature is the ability to set velocity limits that are consistent with each patient's ability to control his own wheelchair. Closed loop feedback is achieved by adding a tachometer or comparable device to measure the output at each motor shaft and comparing the actual velocity of the wheelchair to the referenced value determined by the chin controller (or joystick) depression. On a descending grade, velocity is held to a desired value with minimal input control motions. Closed loop control permits limiting velocity to preset values yet achieves full motor torque to overcome hills and obstacles. This feature is expected to contribute to improved controllability and safety for the highly disabled person.

Closed loop control has been applied experimentally to both chin and hand controllers utilizing electromechanical tachometers. This system works well but is very expensive due primarily to the cost of the tachometers. New solid state bidirectional pulse type photo-tachometers have recently become commercially available for under $100. Future models of the closed loop controller using these tachometers could be marketed at a reasonable price.

Another feature of the APL wheelchair controllers is the addition of electronic filtering in the speed control loop. This eliminates unwanted velocity perturbations caused by head motions (or hand motions on a joystick) which may occur when negotiating bumps and rough terrain. This filter is designed to filter the speed control without affecting steering response, thereby resulting in smoother motions for persons with poor hand or chin control. The results of tests of this filtering scheme with poor hand or head control over rough terrain have been highly favorable.

Microprocessors for Wheelchairs?

The question has been raised relative to the potential merits of the low-cost microprocessor to wheelchair controllers. One model 3P E&J wheelchair has been modified to use a microprocessor controller. In this instance the electronic cards were removed from the E&J controller, keeping only the power output stage and power relays. A microprocessor controller was designed and fabricated using the latest integrated electronic chips and a single chip microprocessor. Signal conditioning and filtering can be readily changed in the programmable memory. This approach enables changing the characteristics of the controller to suit the needs of the individual user. New braking logic enhances safety. Joystick input, APL chin device, or puff and ship inputs may be utilized with the necessary interface modifications incorporated into the software. The initial experimental model used conventional open loop control and was sensitive to the dead zones of the power stage relay system. Incorporation of closed loop control utilizing low-cost pulse-type optical tachometers is planned for future models.

CONCLUSIONS

Motorized wheelchairs provide mobility for a substantial number of disabled persons who are too weak to hand propel themselves in nonpowered wheelchairs. This mobility enhances the potential of such people for self-fulfillment. However, the design of currently available control systems greatly limits the user's ability to maneuver motorized wheelchairs easily within confined spaces or to ascend and descend inclines and surmount minor obstacles without abrupt changes in velocity.

The JHU/APL controllers described in this paper illustrate some new wheelchair control techniques. The chin controller is especially useful for persons with no upper limb function. It is cosmetically inconspicuous and fully compatible with mouthstick use. The closed-loop velocity control principle, which has been incorporated into both the new chin controllers and the manual joystick controllers, contributes to smooth operation over obstacles, safety on inclines, and precision maneuvering. It is anticipated that some of these design concepts will be manufacturable within the next few years and that future control systems incorporating microprocessors will enable wheelchair performance to be programmed to fit each user's need more appropriately.

REFERENCES

1. W. Schneider, G. Schmeisser, and W. Seamone, "A Computer-Aided Robotic Arm/Worktable System for the High-Level Quadriplegic," Computer, 41-47 (1981).

2. R. Lipskin, "Ten Years of Wheelchair Evaluation," Wheelchair II Workshop, Bal Harbour, Fla. (13-16 Dec 1978).

3. W. Seamone, "Report of a Workshop," Wheelchair II Workshop, Bal Harbour, Fla. (13-16 Dec 1978).

4. W. Seamone and J. H. Loveless, "Low Profile Chin Controller for Electric Wheelchair," U. S. Patent 4,260,035 (7 Apr 1981).

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CONCEPT FOR A TWO PART WHEELCHAIR SYSTEM

Stephen E. Blackman

Syracuse University, Department of Industrial Design

ABSTRACT

This paper describes and details a concept for the design of a manual wheelchair based on separate and interchangeable seating and frame systems. The goal of this concept is to combine the benefits of the standard "x-frame" wheelchairs and the new sport wheelchairs into a flexible wheelchair component system. This system allows the easy assembly of a wheelchair that can both properly suit the postural or supportive seating requirements of an individual (as the standard x-frame wheelchairs are know able), and also with the proper connecting frame system enhance his mobility (by using technology from the lightweight sport wheelchairs). The emphasis during this project was to maximize performance, adaptability and carefully consider aesthetics. A working scale model has been built and is used here to demonstrate this two part wheelchair system.

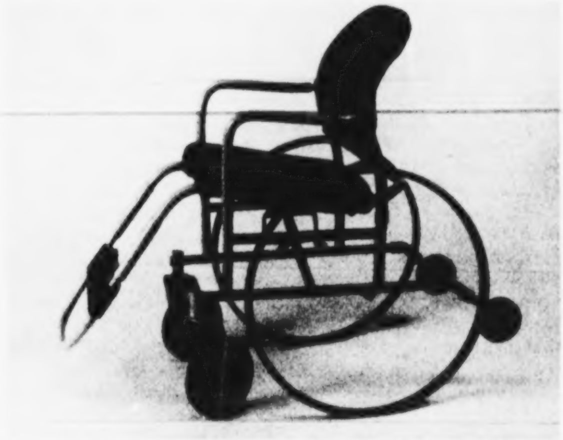

FIGURE 1 ¼ scale model of wheelchair

INTRODUCTION

In light of the increasing trend toward environmental and building accessibility in this country, it is easy to see why the average manual wheelchair user is getting outside more so today. However, the wheelchair of this user, the standard "x-frame" wheelchair, which has always been so common, tends to show the limits of it's performance with this increased outdoor use. At the same time the rapidly developing area of sport wheelchairs shows us many new and innovative approaches which make them more adaptable to this new accessibility. By the same token however many of the sport wheelchairs show their downfall in their lack of adaptiveness to certain postural, supportive and accessory requirements that many users find in the standard x-frame chairs. Therefore very simply, this project deals with this middle ground of benefits, derived by combining the desirable aspects of the standard manual x-frame chairs (such as its adaptability) with the innovations and designs of the sport wheelchairs (such as their performance and aesthetics).

This project began with a thorough examination of the development of the wheelchair from its historic beginnings, up to and including much of the current research being done on manual wheelchairs and their component parts. My research also included many user interviews to collect comments and directions, a thorough review of currently manufactured wheelchairs available in this country, and much first hand experience. The information collected seemed to show a growing number of paraplegic wheelchair users with new needs and new requirements from wheelchairs today. By condensing these needs, three general areas of concern were identified, these were: performance, adaptiveness and aesthetics.

OBJECTIVES

The performance criteria deals with the need for better mobility, both in the operation and transportation of the wheelchair. First the user needs a wheelchair that is lightweight, strong and maneuverable to overcome obstacles such as inclines, curbs and tight spaces. Secondly the user should have a favorable mechanical advantage for propulsion as far as seat angle, placement and center of balance is concerned. During transportation the lightness of the chair itself is important, whether folded and stored by the user himself or someone else. The method of folding and final storage size are also important performance criteria.

The wheelchair must adequately adapt for the users comfort. The wheelchair should be flexible enough to be used by the largest range of users as possible, each with their own individual requirements (i.e. postural, theraputic, supportive, etc.). The wheelchair should allow the user to easily change certain parts or accessories for different conditions and environments encountered. It should also use as many parts as possible that can be interchanged with other manufactured wheelchairs and even with certain bicycle parts.

The last and most overlooked criteria is aesthetics. In addition to functions conditioned by technical, anatomical and therapeutical considerations, one must also pay particular attention to the psychological: the visual design of the wheelchair. Whether it is the choice of options, fabrics, colors or the total design, the aesthetics are an important part of the design and should be incorporated within the engineering stages and not merely as a cosmetic afterthought.

CONCEPT FOR A TWO PART WHEELCHAIR SYSTEM

For the most part the wheelchair is the most noticable part of the clothing of the user. The user should have a choice in choosing and changing this "clothing" and its accessories. Therefore aesthetic considerations should be a very consciously designed aspect within the total design of this wheelchair.

DESIGN APPROACH

Two part system concept

By using these three criteria as guidelines this wheelchair called for a certain amount of flexibility in its design to adapt to the many requirements of each criteria. This flexibility came in the form of separate seating and frame elements: the major concept behind this project. The idea of an interface between seating and frame systems allows for a wide degree of choice and proper fit of the right seat or frame for each individual. It also allows for changes or replacement due to growth or special mechanical requirements, and allows a choice for appearance. Furthermore within each of these two systems certain user controled adjustments also exist to allow a further degree of individualization among each wheelchair.

Seating System

As shown in the diagram the seating unit consists of a back, lower seat section, arms and a front foot bar (or footplates if desired). The back section includes the upholstery and the frame which it is stretched around. Together they follow and support the lumbar curve of the back, this back section is also adjustable in height at the connection point with the frame. The lower seat section is slight angled down in the back to help prevent the user from sliding foward out of the seat. Along with the back section the whole seat has a degree of height adjustment. This is one of the chairs' adjustments to allow for the optimum body angle and angle of grip of the handrims during the propulsion of the chair. (This adjustment is made at the point of connection with the frame). In addition the lower seat upholstery has a zippered pocket to accomodate and adjust to a variety of aftermarket cushions (i.e. gel, water, foam, air, etc.). The seating material would be a breathable, washable, fireresistant material like a nylon cordura fabric with wide velcro pads underneath to both secure the seating upholstery in place and to allow for the perferred amount of sag in the lower seat section. Both the upper and lower seating upholstery can be changed as one changes their own clothes, for the weather or the occasion (i.e. waterproof or warm, formal or sporting). The upholstery can also be color coordinated with the colorful epoxy coated tubing of the frame.

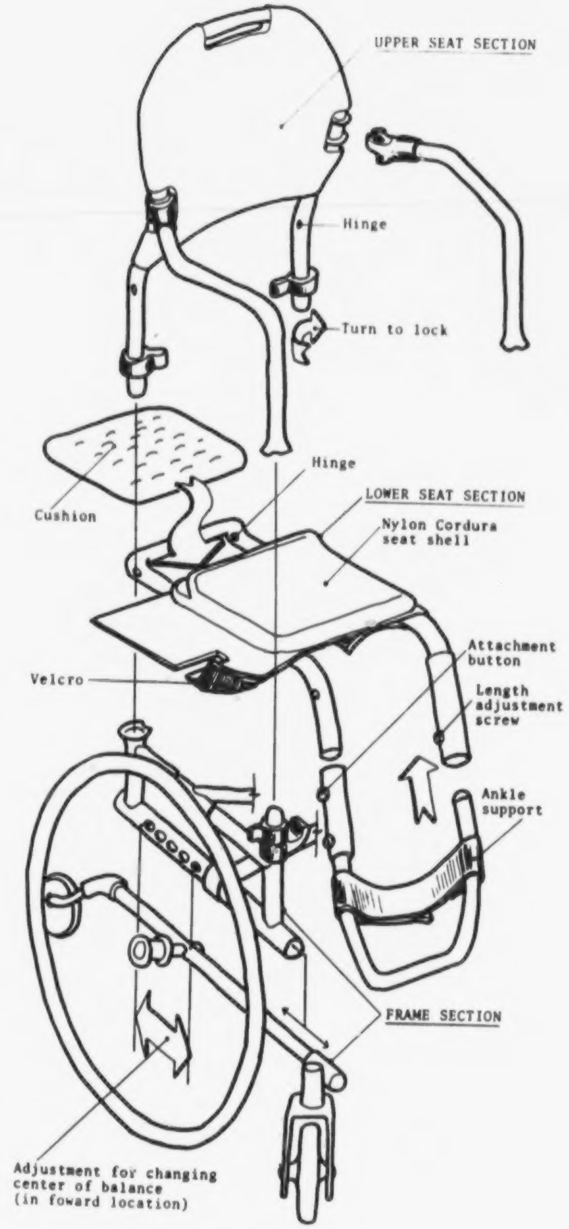

FIGURE 2 -exploded view

Another advantage to a separate seating and frame system is that when storing or transporting the wheelchair, these two light weight separate collapsed pieces are easier to store then the traditional single large heavy folded wheelchair. This is especially true when transporting them inside a car. The seat itself detaches from the frame by folding the lower seat section upward into the back section. The arms, if attached, can be swung inward to join with the uplifted lower seat section. The entire seat unit can then be unhooked from the frame and pulled upward to remove it as a collapsed unit, for easy storage or replacement.

Frame System

After the seating unit has been removed, the frame very simply folds up into itself by picking up the center handle (see illustration). Basically it folds up into a package not much longer then the diameter of the drive wheel. The wheels are each cambered outward to provide a more stable stance and a better angle for the user to propel the wheels. Seemingly this would result in a wider package when folded. The compact width of this folded frame however very nearly compensates for this extra dimension of the cambered wheels. The total folded width is almost similar to that of a standard folding x-frame wheelchair. With the shortened frame and lightweight tubing the total weight of this chair would also be comparatively less then the standard x-frame wheelchair which is made of stainless steel.

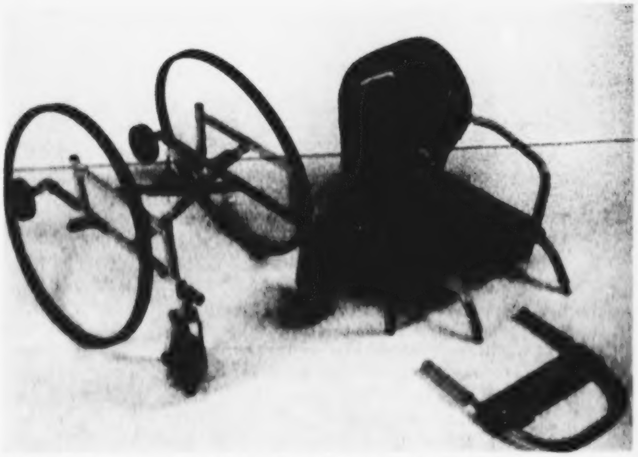

FIGURE 4 -wheelchair disassembled

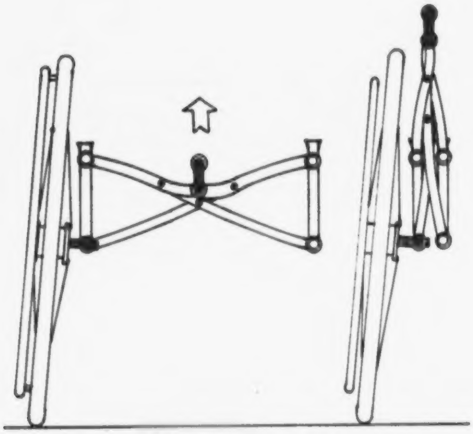

FIGURE 3 -folding frame mechanism

Another feature of this chair is that the users center of gravity can be adjusted for; if the user is a double amputee or if he would just like to adjust the chair for a different center of balance, to make it easier to "pop wheelies" (to go over obstacles like curbs). The adjustment basically involves moving the drive wheel hub foward or backward in relation to the frame (see illustration). This drive wheel is connected to the front caster and rear wheely wheel through a tube within the frame, so as always to keep these three wheels in a constant and optimum relation to one another.

CONCLUSION

The true test of any wheelchair should be through extended user evaluation. However at this stage this paper is merely trying to emphasize the concept of the two part wheelchair system, its innovations and claimed advantages over the standard x-frame wheelchair. Through discussion with many individuals and agencies, the need for this type of wheelchair in our increasingly accessible society seems justified. To see first hand if this theory holds truq a full scale prototype of this wheelchair is presently in the works.

CONTRIBUTOR:

Stephen E. Blackman
1425 Eric Lane
East Meadow, NY
11554

AFFILATION DURING PROJECT

Syracuse University,
Dept. of Industrial Design
Thesis Project

5.12P

CUSTOM POWERED WHEELCHAIR SYSTEM FOR A CHILD WITH FOUR EXTREMITY REDUCTION MALFORMATIONS

Simon P. Levine* and Jane C. S. Perrin†

*University of Michigan Hospitals, Ann Arbor, Michigan
†William Beaumont Hospital, Royal Oak, Michigan

INTRODUCTION

Independent mobility is of the utmost importance and should be made available to children at the earliest possible age. Very young children, though, are rarely provided with a powered mobility aid even when it is the only means for effective mobility (1). A number of young children have been successfully provided with powered mobility aids through our department. All of these have been commercial systems, mostly requiring only minor modifications. A case study is presented describing the provision of a custom powered mobility aid for a three year old child.

BACKGROUND

A three year old male with four extremity congenital reduction malformations (functional quadrupedal amputee) was referred for "mobility evaluation". He was reported to have "bright normal intelligence, normal speech, and come from an excellent home". He had bilateral upper extremity prostheses, a bucket prosthesis, and an Ontario swivel walker, but none were used with much success.

METHODS

Evaluation

The patient showed limited control of his upper and lower extremity stumps due to their size and configuration. He was able to move around in a local environment by rolling and scooting. He did not exhibit adequate capabilities for effective use of a manual wheelchair, cart, or tricycle and so a powered mobility system was considered.

An Everest and Jennings model 3P wheelchair was used to evaluate his joystick control capabilities. Both upper and lower extremity control were evaluated with a 2 inch ball mounted on the joystick. The patient grasped the concept of joystick operation in a brief time. He was able to control the wheelchair to a limited extent with both upper and lower extremities. Sufficient control was exhibited to conclude that he would be able to operate a powered mobility system with apppropriate interfacing and training.

Prescription

Commercial powered mobility systems as well as a custom built wheelchair with powered seat elevator (similar to a prototype developed for automotive side entry at the University of Michigan Rehabilitation Engineering Center) were considered. The advantages of a commercial over a custom system included cost, serviceability, reliability, and delivery time. The commercial systems, however, also had drawbacks. A powered cart might allow independent transfers but would have a limited operating environment (due to its height) and would be rapidly outgrown. A commercial powered wheelchair would also have a limited operating environment due to its fixed height which would additionally prohibit independent transfer.

The proposed custom system had a power seat elevator allowing user positioning of seat height from 4 to 24 inches off the ground. This feature permits the system to be used in a wide variety of environments and allows independent transfers to and from the floor and other surfaces of various heights.

The custom system was selected on the basis of the following conditions:

1) The UMREC automobile side entry wheelchair was available as a model, minimizing cost and delivery time.

2) The wheelchair design allowed for use of a standard control system, drive train, and other components.

3) A local dealer was found to service and maintain the wheelchair.

4) Funding for the wheelchair was obtained from a state agency with cost overruns subsidized from other sources.

Construction

Design criteria and construction methods are presented in another paper, submitted for the student design competition at this meeting. The chair is shown in Figure 1 with the seat in the fully elevated position.

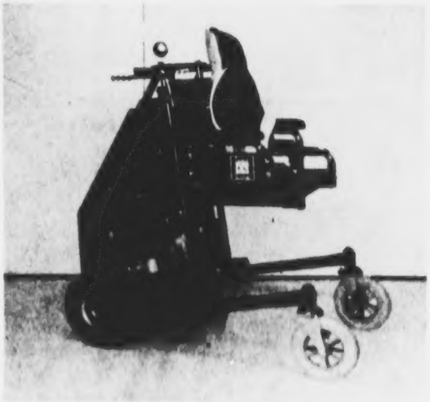

Figure 1. Powered wheelchair with seat elevator.

Fitting and Training

Fitting and training were done concurrently with construction to minimize delivery time. A custom formed seating orthosis was fabricated by the patient's orthotist. An interface for stump operation of the joystick was developed initially, with use of the patient's prostheses to be considered at a later time. The interface used was a sectioned hollow rubber ball (two inch diameter) attached to the joystick, capable of accepting the patient's dominant stump.

The childs capability to transfer into and control the wheelchair steadily improved over the course of three visits. By the third visit he was able to independently transfer into the chair, raise the seat, maneuver the chair, lower the seat, and dismount. Figures 2 and 3 show the child in these activities. Safety issues were repeatedly discussed with the child and his parents. The wheelchair was delivered at the conclusion of the third training visit.

RESULTS

The patient is now training with the system at home and showing progress. The range of environments in which he is allowed to operate it are being temporarily restricted due to his age and the power and weight of the wheelchair. It is expected that he will be able to use the wheelchair at school, home, and play in coming years.

Figure 2. Child transfering into the wheelchair.

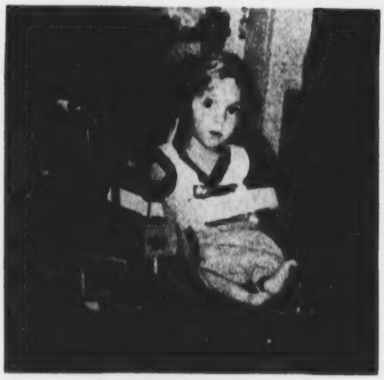

Figure 3. Child driving the wheelchair.

DISCUSSION

Custom assistive devices are rarely provided through the Rehabilitation Engineering Division, University of Michigan Hospitals. When they are, every effort is made to be sure they offer considerable advantage over commercial devices, are cost effective, servicable, and can be provided in a timely fashion. The case presented here is an exception where the compromises of a (modified) commercial system were too great and the resources appeared to exist for fulfillment of the conditions listed above.

A wheelchair with seat elevator offers advantages to many users. This feature allows an individual to effectively work at surfaces of varying heights and facilitates transfers. It can be powered or manual and incorporated into either powered or manual chairs. A commercial system offering this feature would significantly enhance the capabilities of many wheelchair users.

ACKNOWLEDGMENTS

The dealer servicing and maintaining this system is Adaptive Wheelchairs Inc., Detroit Michigan. Subsidization for this wheelchair came from the University of Michigan Rehabilitaiton Engineering Center (Grant # G008200047, National Institute of Handicapped Research, U.S. Dept. of Education)

REFERENCE

1. Trefler E., Cook H.: "Powered Mobility for Children". **Proceeding of the International Conference on Rehabilitation Engineering**, 1980.

Address

Simon Levine, M.A., M.S.
Director, Rehabilitation Engineering Division
Dept. of Physical Medicine and Rehabilitation
E3283 University of Michigan Hospitals
Ann Arbor, Michigan 48109

5.13P ALTERNATIVES FOR CONTROL OF WHEELCHAIR RECLINERS

S.D. Braswell, J.R. Buckett

Case Western Reserve University/Rehabilitation Engineering Center

ABSTRACT

Independent control of a wheelchair recliner is perceived to be a benefit by people with high level spinal cord injuries. This represents a separate task from controlling a wheelchair, so that a user must have enough suitable control sites. Often, these separate control sites are not realizable. We have implemented two different recliner controllers, including one that is compatible with the shoulder position wheelchair controller developed at this center. These controllers offer ease of operation, low cost and the possibility of many different types of control inputs.

INTRODUCTION

A recurring problem of people with high level spinal cord injuries is control of wheelchairs and their associated devices, usually a power recliner. A recliner is a useful accessory, that aids in weight shifts and gives an increased sense of independence. Unfortunately, many commercial power recliners do not have suitable controls. We considered the possibility of interfacing the shoulder position wheelchair controller with a power recliner when we were approached with this problem by two full-time users of the shoulder control system. Two different solutions were proposed and evaluated.

Normally, a recliner switch is mounted on an armrest, a headrest, or on a chin controller bracket. To control a recliner, two separate switch functions are needed, one to recline up and one to recline down. Since the target population of the shoulder controller is the C3-C4 level spinal cord injury, the use of armrest mounted switches is precluded. Using a recliner switch mounted on a chin controller bracket would defeat the purpose of using a shoulder controller.

Both clients intended to buy Everest and Jennings 3P wheelchairs equipped with a Falcon recliner. This recliner is controlled by a large single-pole double-throw switch. Unfortunately, this switch is difficult to operate especially for people with high level spinal injuries. Our initial design goal was to replace the switch with a controller that was simple, low cost and easy to operate. Our second design included the goal of a high degree of compatibility with the shoulder controller.

BACKGROUND

The shoulder position controller was developed to serve as an alternative wheelchair controller for people with high level spinal injuries (1,2). The original application of this device was as a plug-compatible joystick replacement for E and J wheelchairs. Since then, the shoulder controller has been modified for use as a replacement for the Med chin controller and to replace the joystick of the Invacare power Rolls wheelchair.

Currently, there are three people who are full-time users of the shoulder controller, and several who are occasional users. We also have several prospective candidates waiting for new systems.

MATERIALS AND METHODS

The recliner unit that we proposed to modify is the Falcon recliner. This unit consists of a switch and a motor/actuator. Additionally, there may be limit switches to regulate recliner excursion and additional actuators for raising and lowering headrests, etc. The power for this unit is supplied by a 12 volt battery, usually one of the wheelchair drive batteries. The power leads are routed through the switch to the motor. The switch controls the polarity of the voltage, which controls the direction of travel. Since the switch must carry all the motor current, it must be large and bulky.

An obvious improvement is to replace the current carrying switch with relays. Now the control switch need only activate the correct relay to achieve the desired reclining action. This permits the use of many different types of switches. Possibilities include puff-sip switches, strip switches and bump switches. We chose to use two double-pole double-throw relays and wire them in such a way that only one could be activated at a time. This prevents the possibility of shorting the battery.

The first controller we built was for a client who had purchased an E and J 3P wheelchair and a Falcon recliner without limit switches. We used our relay box to replace the control switch. After an evaluation, we decided to implement a puff-sip control. Pneumatic switches were installed in the relay box. Plastic tubing was run to a bracket holding a mouthpiece. The bracket was mounted on the side of the wheelchair and positioned so as to be accessible by the user. The relay box was mounted under the wheelchair. Two attendant switches were mounted on the rear of the wheelchair and connected in parallel with the puff-sip switches.

We consider this system to have many advantages as a general purpose recliner controller. The unit is very simple to fabricate, the cost is nominal and it is adaptable to a wide range of control inputs. For our specific application, there are some drawbacks. The system requires a control site separate from those used by the shoulder system. The second disadvantage is that the recliner control is not integrated with the shoulder controller. The two units should be interfaced in such a way that if the shoulder control was active the recliner would be locked out and if the wheelchair seat was not at an acceptable angle for driving, the shoulder controller would not operate.

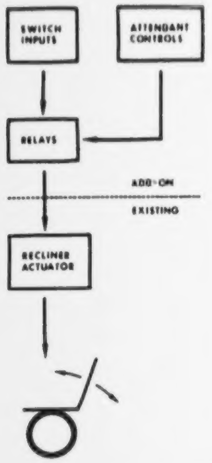

Figure 1. Block Diagram of Stand-alone Controller

When a second user of the shoulder control system asked about a recliner control, we decided to address ourselves to correcting the shortcomings of our first design. Our first objective was to build a recliner controller that could "talk" to a shoulder controller and thus exchange status information. The second design objective was to derive all the control signals for the shoulder controller and recliner from a single source.

In this case, the client had used a headrest switch for the shoulder controller. The only way to discriminate different switch signals is on the basis of duration. Our initial thought was to design a classical state machine controller. The hardware design for this type of controller was too complex and not flexible enough. We then investigated the possibility of a microprocessor based control. This seemed to be a good choice as it offered many advantages, including simple hardware design, definition of control algorithm in software and ability to perform complex timing functions for control switch input discrimination.

Based on previous experience, we chose to design a two chip microprocessor system based on the Motorola MC146805E2 CMOS microprocessor. This microprocessor is ideally suited for low end controller applications. It has 16 input/output lines, an 8 bit timer and 112 bytes of RAM on-board. For program memory, an Intersil 6654 512 x 8 CMOS EPROM was used. This chip has an address latch on board and interfaces directly to the multiplexed address and data bus of the microprocessor. With the addition of a few miscellaneous components the controller hardware was completed. One of the real advantages of a microprocessor based controller is that everything may be defined in software. One need only burn a new EPROM in order to change the characteristics of the system.

In this case, we were dealing with an E and J 3P wheelchair equipped with a Falcon recliner with limit switches. Our other consideration, besides recliner control, was communication with the shoulder controller electronics. For interface purposes, the recliner controller sends a switch signal to the shoulder controller that "fakes" the switch signal the shoulder controller expects from the headrest switch. The recliner controller monitors the status of the shoulder controller via an active/passive line. This takes two of the 16 available I/O lines. Two input lines are used for the normally-open and normally closed switches in the headrest switch. Normally-open and normally-closed switches are used in parallel for safety and redundancy reasons. Their use allows the system to detect broken wire and unplugged cable situations. Two more inputs are used for the upper and lower limit switches. The seat angle at which these are tripped is adjustable. The final input is used for a battery under-voltage detect. There are nine output lines besides the one used to supply a switch input to the shoulder controller. Two of these outputs are used to turn on the up and down relays. The other seven outputs are used to directly control a 7-segment LED display. This display gives the user the system status, including information about whether the shoulder system is active or passive, whether the recliner is going to go up or down and low battery condition. With direct control over the segments, many non-standard characters may be formed. In our current controller we use five characters, 'A', 'P'. 'U', 'd', and 'b', for active, passive, up, down and low battery.

Once the hardware was designed and the inputs and outputs defined, it was necessary to develop the software for a control algorithm. It was decided to define three different headrest signals, short, long and failsafe, in order of duration. The durations could be set to any arbitrary value. Short signals cause the shoulder controller to toggle between active and passive. If the wheelchair seat is not against the upper limit switch, the system will not be able to go active, thus preventing the chair from being driven when it is reclined. The long signal is used to activate the recliner. The recliner toggles between going up and down. Once the reclining action has started, it is terminated by any headrest switch signal or by a limit switch. If the wheelchair is active, it is first switched to passive before the reclining action begins. The failsafe switch is used to cut wheelchair power in the event of a major malfunction.

In our actual implementation of this system, there are two boxes mounted under the wheelchair. One is a slightly modified shoulder controller. The other contains the recliner controller and relays. Mounted on the back of the wheelchair is an interface box with an on/off switch, two pushbuttons for attendant control of the recliner and a jack to connect the shoulder transducer. The user display was mounted on a bracket from the front of the armrest, and positioned so that it could be easily seen, even when reclined.

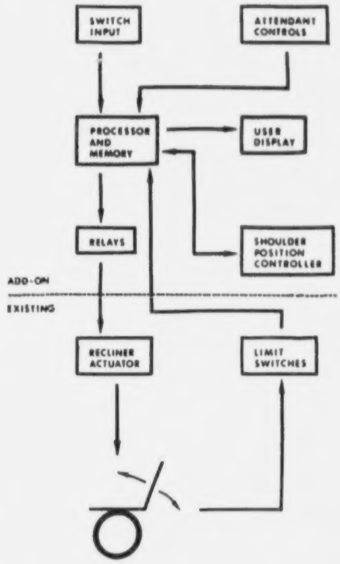

Figure 2. Block Diagram of Integrated Controller

The advantages to this integrated system greatly outweigh the disadvantages. Using only one control site for both driving a wheelchair and controlling a recliner would be a difficult task without the use of a microprocessor-based controller. Another advantage is that the control algorithm is completely defined in software. This allows the controller to be easily customized for individuals. The only disadvantage with this system is that it is not as simple a control task for the user to learn.

RESULTS

In actual use, both systems have proven to be highly successful. Both clients have indicated that their respective systems are highly acceptable. Both systems have a good degree of cosmesis, in accordance with the aim of using the shoulder controller.

The puff-sip controller was mastered by the user with less than a half-hour of training. The integrated system took a little longer to learn, about 4 hours, but represents a more difficult control task. With feedback from the user, we were able to adjust the optimum durations for the short, long and failsafe signals. One minor complaint about this system was that the chair could only be driven when the seat was against the upper limit switch. The user felt that he would like to be able to drive the chair when the chair back was anywhere between 80 and 90 degrees. Since both clients were experienced shoulder control users, they had no problem with this aspect of their training.

CONCLUSIONS

We have designed, built and tested two different types of recliner controllers. Both are relatively easy to fabricate, have a nominal parts cost and are versatile in the number of different control inputs possible. The stand-alone controller represents a viable replacement for the control switch on a stock Falcon recliner. The integrated controller is a good, but not perfect, solution to the problem of recliner control while using a shoulder controller.

The development of the integrated controller led us to start investigating the development of a totally microprocessor-based system. This proposed system would offer many enhancements. A potentiometer could be used to read in actual seat angle, allowing more flexible control of driving modes. Such a system would also be able to control multiple actuators (headrests and leg rests, for example) independently. This proposed system would also improve the functionality of the shoulder system.

REFERENCES

1. 4th Annual Progress Report - Rehabilitation Engineering Center at Case Western Reserve University, Cleveland, Ohio, May, 1980 to April, 1981.

2. Buckett, J.R., Peckham, P.H., and Strother, R.B. "Shoulder Position Control: An Alternative Control Technique for Motion Impaired Individuals". Proceedings of International Conference on Rehabilitation Engineering, Toronto, 244-247, June, 1980.

ACKNOWLEDGEMENTS

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Correspondence should be sent to S. D. Braswell, Case Western Reserve University Rehabilitation Engineering Center, Cleveland Metropolitan Highland View Hospital, 3395 Scranton Road, Cleveland, Ohio, 44109.

VINYL VACUUM FORMING

Douglas A. Hobson, Billy J. Seaton, and Nigel Shapcott

University of Tennessee Center for the Health Sciences
Rehabilitation Engineering Program
Memphis, Tennessee

OBJECTIVE

The objective of this project has been to develop an affordable basic vacuum forming machine and related techniques that will facilitate the fabrication of contoured and aesthetic seating inserts.

BACKGROUND

A major contribution that both engineers and industrial designers can make to the lives of the physically disabled individuals is the development of tools that can expedite the evaluation, fabrication, and provision of appropriate technical aids by rehabilitation professionals, durable medical equipment specialists, and their support staff. Examples of tools that have been developed in parallel fields by technical researchers are: the Berkley Brim Fitting equipment used by prosthetists to make quadralateral sockets for above knee amputees; the pre-fabricated plastic spinal and ankle-foot orthosis used by orthotists; and more recently, the gait analysis equipment used by orthopedic surgeons to determine locations for surgical procedures required to improve ambulation of children with neuromuscular disorders.

In the field of specialized seating the Simulator concept associated with several systems of specialized seating are further examples of attempts to develop tools that will permit families and clinicians to make more intelligent decisions regarding the appropriateness of these approaches prior to making considerable financial committments.

Other recent advances have been made in developing improved tools to facilitate the quantitative evaluation of severely disabled individuals seeking means to control powered wheelchairs and communication aids.

The vinyl plastic vacuum forming machine represents an attempt to develop and make available a basic tool that facilitates the economical fabrication of aesthetically pleasing seating inserts. Most facilities that are providing specialized seating services do not have sufficient volume to have staff with expertise in upholstery skills. This presents a problem when the stage comes for the final finishing of a seating insert. As a result a compromise is usually made, the results of which are often costly in terms of the labor involved and the aesthetic quality of the final product.

Vacuum formable vinyls are materials that are now readily available from industry. They are used in a variety of applications such as recreational vehicle seats, tractor seats, automobile upholstery, etc. These materials are available in a variety of thicknesses with reasonable color varieties. Extruded trim materials are also available for giving products a professional edge finish appearance. Vacuum forming of plastics is a well established procedure within industry and also the orthotics field. More recently, rehabilitation engineering research and service programs have utilized this industrial process to fabricate a wide range of low volume adaptive devices, i.e., MPI seating system, foot supports, wheelchair trays, and housings for communication aids and interface devices.

The focus of this task is to make the vacuum forming process and related vacuum-formable vinyls available as a basic tool to facilities providing specialized seating services.

CONCEPT

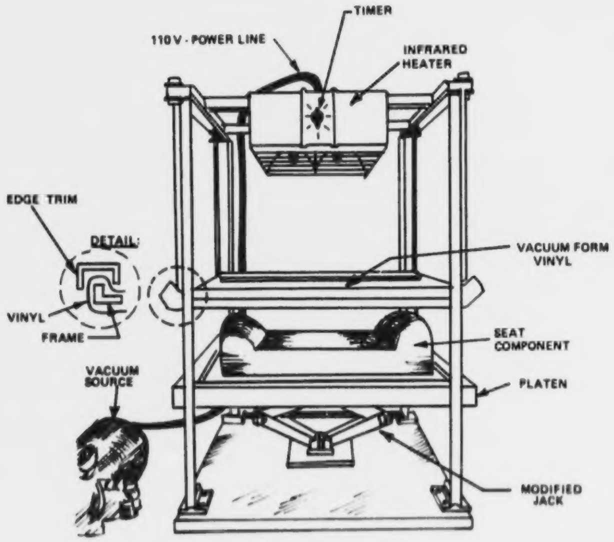
The basic vacuum forming process involves the heating of a sheet of plastic material (in this case vacuum formable vinyl) until the material is moldable and can be readily stretched into any shape. This is followed by stretching the heated plastic over a shape (mold) that one wishes the plastic material to ultimately assume. A vacuum is then drawn on the material and atmospheric pressure forces the moldable plastic around the mold shape. Cooling the plastic (vinyl) while held in the newly formed shaped will cause the material to remain in the desired final shape.

In seating applications, the mold is a contoured seat or back insert component. The insert is commonly fabricated from foam and plywood, or in the case of UT-REC application, a polymerized bead/urethane matrix. Elaborate automated equipment exists to heat the plastic, transport the heated plastic, infuse the mold into the plastic, form a vacuum seal, provide the vacuum source, and finally apply the vacuum. The cost of such equipment would be prohibitive for most service facilities providing specialized seating. Therefore, the challenge of this project has been to retain the basic features of the vacuum forming process, but package them in a simple machine designed specifically for seating applications. Further design constraints were that the machine should have a market value not to exceed approximately $1,500.00 dollars, and that the machine could be operated by only one person.

RESULTS

A Prototype VVF machine has been produced which meets the above criteria. Local trials over the past year has lead to a reduction in the labor skills required, enhanced quality of the final product, with overall cost reductions.

a.) Description - The VVF machine consists of a basic frame fabricated from 1 inch square steel tubing (See Figure). Suspended from the top of the superstructure on four rigid 3/4 inch diameter threaded rods is a 24" x 24" fixed frame, fabricated from 1 inch steel angle. The infrared heat source is located at the top of the main frame. The threaded rods also allow periodic adjustment of the distance from the heat source to the fixed frame to increase or decrease the amount of heat being applied to the vinyl sheeting. The infrared heater has been modified to accept a timer which cuts off the heater at a pre-selected time. The timer has a maximum time setting which serves as a safety feature.



Located on the base structure is a standard scissor jack which has been modified to accept a standard variable speed hand drill. Further modification to the top plate of the jack permits the placement of the platen/vacuum chamber. The platen is fabricated from plywood in such a manner to create a vacuum chamber within the platen. Tubing protruding through the outer edge of the platen permits the attachment of a vacuum source, so that a vacuum may be created within the vacuum chamber of the platen. Holes penetrating the top surface of the platen allow evacuation of the air space between the vinyl and the mold once the platen is moved up and sealed air tight around the lower edge of the fixed frame.

b.) Operation - The heater is turned on for approximately five minutes to preheat the fixed frame. Next, a 27" x 27" piece of vacuum formable vinyl is clamped in the fixed frame. The infrared heater is set for 10 minutes in order to heat the vinyl. During this time fabric adhesive is applied to the surface of the seating component. With the platen in the down position the seating component is then placed in the middle of the platen. After approximately six to eight minutes the vinyl is ready for forming. Using the variable speed hand drill to drive the jack screw and with the vacuum pump running, the platen is elevated until an airtight seal is obtained against the fixed frame. (Observation of the movement of the vinyl indicates when a seal has been obtained) This step will stretch the vinyl tight and prevent the formation of any wrinkles in the vinyl. With the heat still on the vacuum will begin to evacuate the air space further stretching the vinyl around the seat component. Some further hand forming around the lower edges can take place at this time.

The heat source is then turned off and the vinyl is allowed to cool for about five minutes. The adhesive plus the newly formed shape of the vinyl sheeting will provide an intimate cover over the contours of the seat. Once cool, the clamping is removed from the fixed frame, the platen lowered with the hand drill, and the seat component and vinyl cover removed from the machine. Edge finishing of foam and plywood components can be accomplished in the traditional manner of further hand stretching and stapling around the bottom surface of the plywood. The BSI system has edge trim already around the lower edge of the plastic tray. This trim is used to clamp the outer edges of the vinyl securely to the plastic tray to give a final professional appearing edge finish. Total time - approximately 30 minutes per component.

FUTURE PLANS

The prototype unit has received extensive shop trials over the past four months. The concept of being able to produce a useful low cost vacuum forming machine is most valid. As could be expected the trials have lead to ideas for improvement. A second generation unit is currently being completed. This unit is much more compact, (bench top) and uses components that are readily available and relatively inexpensive.

The new prototype has been designed to be as simple and cost effective as possible. It consists of a box base used as the mold and frame support, and an infrared heat source. The box base is also used to mount; a control system, consisting of timer and switching; a vacuum pump; a variable vacuum control; and a De Sta Co clamp for locking the frame.

To operate the machine the frame with vinyl is supported in front of the infrared heat source. Adhesives are applied at this time and when the forming temperature is reached the vacuum pump is turned on and the frame is pulled down manually over the mold. The De Sta Co clamp is then used to seal and lock the frame. The variable vacuum control is used to control the rate at which the vinyl is pulled.

Douglas A. Hobson
University of Tennessee
Rehabilitation Engineering Center
682 Court Avenue
Memphis, Tennessee 38163

5.15P ADVANCED WHEELCHAIR ACTIVITIES TRAINING AID/WHEELCHAIR RECLINER

D. F. Law, Jr., L. Hinrichsen, R.P.T., and C. Nordstrom, R.P.T.
Woodrow Wilson Rehabilitation Center: Fishersville, VA 22939

INTRODUCTION

Occasionally, a paraplegic with a coincidental cervical instability and a halo vest will arrive in Physical Therapy clinic for instruction in advanced wheelchair mobility. The intent of this paper is to describe an effective solution to this problem.

BACKGROUND

During mastery of wheelie and related activities, the patient is at risk of falling backwards with serious consequences. The alternatives, which may not be desirable, are to delay training until restrictions are lifted, or to provide a staff member to "spot" each person in training.

If training is delayed, the patient may experience a great deal of peer pressure to try wheelie activities. Often this pressure causes the patient to risk independent experimentation.

In any case, the delay can be rather long and proportionately lengthen the duration of his program.

DEVELOPMENT

Recently, our Physical Therapy Department and Rehabilitation Engineering Services developed a simple yet effective "add-on" kit which allows safe completion of most basic wheelie activities.

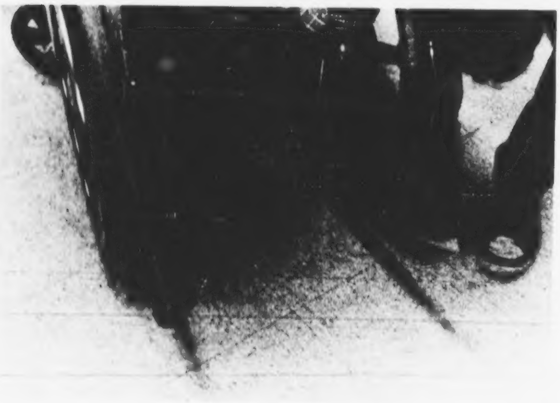


FIGURE 1 FIRST PROTOTYPE

PROTOTYPES

The first prototype consisted of a set of tubular members which extended the two protruding tubes on the rear of the wheelchair frame. (See Figure 1.) The extensions were attached by drilling through both tubes, after properly alignment, and inserting a "pip" pin.

Problems

The length of the add-on device was found to be very obtrusive when maneuvering the wheelchair. It was also feared that it could produce a braking action when contacting the floor during rearward movement. This braking effect could conceivably bend the frame members or even flip the wheelchair backwards.

Revisions

For greater strength and cosmesis, the final version of this kit was fabricated from 1/4 x 3/4 inch steel flatbar with two 7/8 inch set-screw collar clamps for attachment. In addition, a small roller was added to each extension. These rollers contact the floor to prevent marring and to allow rolling while in the reclined position. (See Figure 2.)

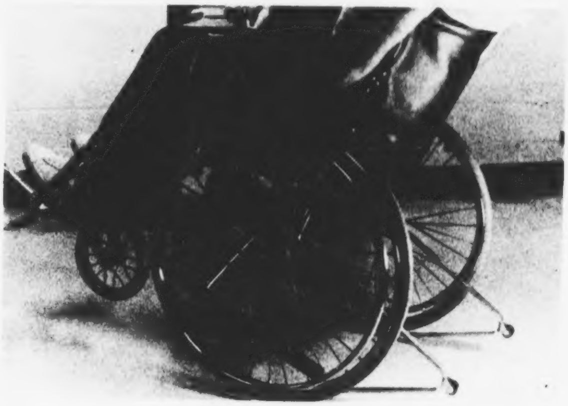


FIGURE 2 REVISED PROTOTYPE

The two components of this kit are attached by tightening the set-screw clamps around the frame members. (See Figure 3.)

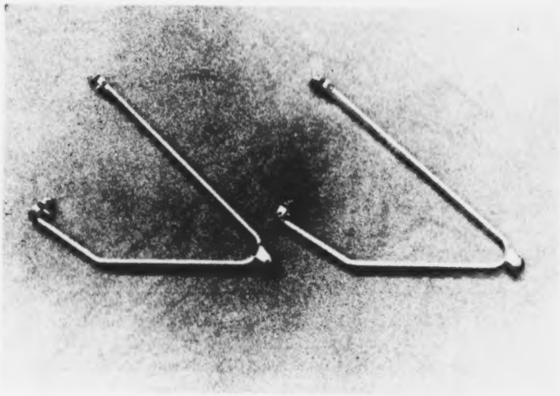


FIGURE 3 KIT COMPONENTS

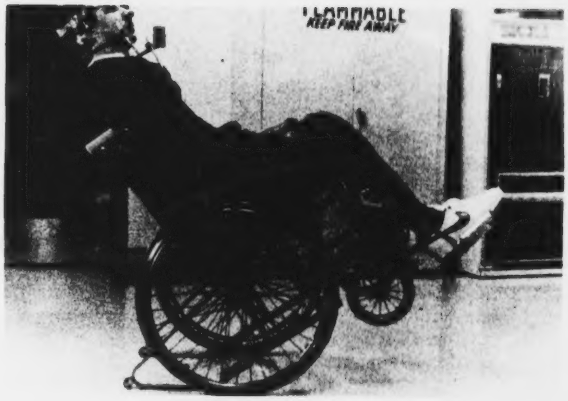


FIGURE 4 PATIENT IN RECLINED POSITION

The degree of recline that the guards allow is determined by the mounting position on the wheelchair.

Proper alignment of the mounting clamps will allow a slight excursion beyond the balance point during wheelie without complete loss of control in a backward direction.

ADVANTAGES & DISADVANTAGES

When the guards are installed, the patient is able to attain a wheelie and practice a glide. The patient is further able to ascend eight-inch curbs, descend two-inch curbs in a forward direction, and descend eight-inch curbs in a backward direction.

Although its primary function is to allow independent practice of wheelies and glides, all of the advanced wheelchair activities may now be practiced with a much greater degree of safety.

The disadvantage, however, is that the user is unable to make forward descent of curbs, ramps or stairs, while maintaining a wheelie. This is understandable, since the kit is designed to prevent the risk of falling rearward while practicing on a horizontal surface.

It should be noted, that it may still be necessary to guard the new student when he begins practice on curbs and ramps, or until forward instability and lateral instability are no longer viewed as hazards.

Another unique feature should be mentioned. The modification now allows the wheelchair to recline slightly past the point of balance until it completely rests on the kit. This produces an instant "recliner," contributing to proper management of dependent lower limb edema[1] and providing a pleasant position for leisure activities. (See Figure 4.)

SUMMARY

The primary purpose for developing this device was to provide a temporary, easily installed kit to be used as a clinical tool in promoting patient independence and safety during the practice of most advance wheelchair activities.

The use of the kit has been very effective in allowing better utilization of staff who would otherwise be required to "spot" each patient while practicing these maneuvers. Also, the reclining stability imparted to a wheelchair by this modification indicates potential for application to non-clinical settings.

REFERENCE

[1] Brunner, L., Suddarth, D., et al. "Edema of the Lower Extremities," The Lippincott Manual of Nursing Practice, Third Edition, 1982, 996-997, and Nelson, P. A. "Recent Advances in Treatment of Lymphedema of the Extremities,"Geriatrics, 21: 162, 1966.

ADDRESS

Rehabilitation Engineering Services
W. W. R. C.; Fishersville, VA 22939

ELECTRICAL WHEELCHAIRS - POWER SYSTEM

Ingemar Brattgård

Göteborgs Universitet Department of Handicap Research

A research and development project concerning electrical wheelchairs has been going on at the Department of Handicap Research at the University of Göteborg for several years. Wheelchair function and design are assessed in relation to users' needs throughout the project. These needs can be formulated in functional terms and mainly comprise mobility and sitting function. The design of the electrical wheelchairs is based on the modular concept in order to provide flexibility with a few models. The main components of the wheelchair are the chassis, the seat unit, and the control unit. At present there are two types of chassis: one for indoor use and one for combined indoor and outdoor use. The new seat unit can be adjusted to the user's anthropometric measurements and is based on a modular system. The work carried out so far has resulted in a production prototype of the wheelchair for combined indoor and outdoor use. This will be demonstrated in connection with presentation of the paper and the main principles will be presented. The emphasis will be placed on the power system, quantitative methods of measuring variables relating to driving and mechanical loading, and different aspects of the design of the chassis and the seat unit.

POWER SYSTEM

The wheelchair's mobility is mainly determined by the design of the chassis and power system. These aspects are particularly important in a wheelchair intended for both indoor and outdoor use. The wheelchair must be able to overcome obstacles, climb slopes, travel fairly long distances without the batteries needing to be recharged and withstand tilting to large angles without turning over. These requirements tend to result in a large chassis which is not suitable for indoor use. By employing near optimal solutions, it is quite possible to produce a combined chassis. The most important factors are the position of the wheels and their size and suspension.

If these requirements are combined with a suitable motor and electronic power system, a reliable product can be obtained. Unfortunately, the introduction of modern electronics has been slow in the wheelchair industry. This has meant, for example, that a feedback speed control system is lacking on most wheelchairs. The possibilities of simple, precise and safe maneuvering are thereby greatly reduced. This part of the presentation mainly will deal with such questions as the choice of motor, design of the control system and electronic power system and chassis layout. The results of our research and development work will be presented. The following are some of the technical data for the wheelchair presented: width, 25"; turning radius (180°), 43"-44"; maximum obstacle clearance, 4"; maximum slope, 30%; range, 20 miles; and maximum speed, 4 mph.

A MEASURING METHOD

The lack of quantitative data concerning such factors as range, speed, and mechanical loading prompted us to carry out our own measurements. Since we could not find any directly applicable measuring method or measuring instrument, we developed our own measuring equipment. We decided that it should not only register different variables but also be capable of carrying out relevant statistical analyses. In the initial stages, the measuring data were registered with a portable tape recorder and analyzed with a minicomputer. The tape recorder was replaced by an A/D converter and a microcomputer mounted directly onto the wheelchair. Most variables could be obtained without the use of special transducers. Instead we registered the motor current and voltage. The distance covered, speed, power, and load on the electronic power system, motor, transmissions, and batteries can be derived from these registrations. After analysis in the microcomputer, the results can be used directly for dimensioning transmissions, motors, and electronic power systems.

The general design of the measuring equipment, which allows one-, two-, or three-dimensional density functions to be created, makes it possible to register a large number of variables and their covariance. We have found registration of the electric current and voltage most useful. The small size (7" x 5" x 2"), low weight (1 lb.), and low power consumption (0.175 W) of the microcomputer-based equipment enable the measurements to be made without significantly influencing the properties of the wheelchair. The data storage capacity and power consumption allow continuous measurements for at least one month. The equipment, therefore, should offer good possibilities of studying the mobility habits of wheelchair users and thereby provide a sounder basis for wheelchair design.

DESIGN ASPECTS

The use of materials that are relatively new in the wheelchair industry, such as extruded aluminum, has made it possible to design a seat unit based on a rational modular system. The modules are attached in a way that provides easy adjustment to the users anthropometric data. Modules are available for electrical adjustment of the leg and back angles and seat height. Fixed and manually adjustable modules also are available. The use of new materials also has resulted in a new styling.

Ingemar Brattgård
Göteborgs Universitet
Department of Handicap Research
Brunnsgatan 2
S-413 12 Gothenburg, Sweden

WHEELCHAIR - SITTING QUALITY

Sven-Olof Brattgård, M.D.

Göteborgs Universitet Department of Handicap Research

A wheelchair must function both as an efficient means of transport and as a comfortable chair. Research and development work concerning wheelchairs so far has concentrated mainly on the transport aspect. Important progress has been made, especially as regards the design of electric wheelchairs. Apart from efforts to solve the pressure sore problem, however, research and development concerning sitting quality has been sadly neglected.

The concept "sitting quality" is a subjective one and covers a wide range of factors. Important factors are the chair's ability to support the occupant's body weight and distribute the pressure on the body surface, stabilize his body posture, and enable him to change his posture. Other important requirements are a comfortable temperature, low humidity, and good ventilation. A third group of factors is not directly related to sitting function but influences subjective sitting quality. An example of such factors is the activity in which the occupant is engaged. Discomfort is easier to tolerate when one's attention is occupied by an interesting activity than when one is just sitting and waiting. Some of the above factors can be measured and their effect on sitting quality can be registered, but it important to keep in mind that "sitting quality" is a subjective concept.

Proper design and prescription of wheelchairs presupposes methods of measuring factors influencing sitting quality. Our research aims at analyzing how different factors influence the possibilities of achieving good sitting quality or sitting comfort. We have studied the following factors:

- the possibility of adapting the wheelchair to the occupant's physique (anthropometric factors);
- the ability of the wheelchair to support the occupant's body weight and distribute the pressure;
- the ability of the wheelchair to stabilize the occupant's sitting posture;
- the ability of the wheelchair to enable the occupant to change posture;
- the ability of the wheelchair seat to provide a comfortable temperature at the seat surface;
- the ability of the wheelchair seat to conduct moisture away from the seat surface.

The latter two factors generally depend on the seat itself rather than on the design of the wheelchair. The first four factors, on the other hand, usually are directly related to the wheelchair design. This paper, therefore, will concentrate on these factors, with special reference to a method of measuring factors essential for good sitting quality which we have developed.

Every human being has individual anthropometric and other characteristics which must be considered in the search for a chair giving good sitting quality. It is only thanks to the human body's unique ability to adapt that standardized chairs can be used at all. The deficiencies that the manufacturer cannot or will not correct, owing to insufficient knowledge or incompetence, inevitably will cause the occupant discomfort. A suitable and flexible basic design is a prerequisite for adaptation of the wheelchair to fundamental individual requirements.

In order to be able to determine the extent to which wheelchairs can satisfy individual anthropometric requirements, we designed a special measuring instrument which enables us to obtain all essential information. The instrument mainly is designed for determination of the wheelchair's sitting quality in relation to anthropometric measurements. By measuring the corresponding dimensions in the individual, it is possible to "class" different wheelchairs as more or less suitable for the person concerned.

The measuring instrument can also be used to determine the extent to which a wheelchair provides a sufficiently large support surface to take up the individual's body weight and distribute the pressure. By combining the instrument with a pressure gauge in the buttock area, the pressure between the seat and buttocks can also be measured. The pressure against the back and arms of the chair can be measured in the same way. When determining the requirements for good sitting quality, it is important to study not only the ability of each support surface to take up and distribute pressure but also how the different support surfaces influence one another and how changes in these relationships influence sitting posture. "Dynamic" measurements are therefore necessary.

One of the great differences between wheelchairs and ordinary chairs is that a person sitting in an ordinary chair normally supports his feet on the floor, while the occupant of a wheelchair generally supports his feet on a footrest. The footrest is usually a prerequisite for use of the wheelchair as a means of transport. The footrest must also have a certain minimum clearance over the floor so that the chair can be maneuvered over obstacles.

Another difference between ordinary chairs and wheelchairs is that wheelchairs are often much more flexible as regards arm height, legrest and back angle, etc. This means that wheelchairs must often be measured under "dynamic" conditions.

An ordinary chair is often tested in relation to the purpose for which it is recommended, i.e., as an office chair, easy chair, etc. The wheelchair usually has to fulfill several different functions. Wheelchair testing, therefore, must be based on a broader spectrum of factors.

A factor that is often specific to the wheelchair is that it must be suitable for people with deviating physique and posture. Ordinary chairs usually can be tested in terms of more general requirements. Wheelchair testing should allow also for the great anatomical variations in size and shape among users. It is therefore less informative to analyze how a "standard person" sits in a wheelchair than to analyze for which people the chair is suitable.

Wheelchair - Sitting Quality

The requirements of providing stability in a certain sitting posture and allowing the occupant to change his or her posture are to some extent conflicting. Although compromise is necessary, it is important to emphasize that it is the individual user who must decide the compromise level, not the manufacturer. In order to provide good sitting quality for a particular user in his or her special situation, the wheelchair must be sufficiently well designed and flexible to allow the level of compromise to be altered. The human body as a biological system is highly dependent on alternation between work and rest, between activity and inactivity in different tissues. If this alternation is not possible, the body's tissues will be affected, leading sooner or later to subjective discomfort and objective changes. The wheelchair occupant's ability to change his sitting posture is dependent on the shape and size of the support surfaces, among other factors. It is important to keep in mind the differences between wheelchairs and ordinary chairs when measuring factors influencing subjective sitting comfort.

Sven-Olof Brattgård, M.D.
Göteborgs Universitet
Department of Handicap Research
Brunnsgatan 2
S-413 12 Gothenburg, Sweden

COMMUNICATION SYSTEM FOR AN AKINETIC, DEAF, MUTE PATIENT WITH NORMAL COGNITIVE ABILITY

6.1

APFEL, Eileen, OTR
Veterans Administration Medical Center
San Diego, CA 92161

ABSTRACT

A 33 year old male sustained a Basilar Artery Thrombosis which left him completely deaf, and paralyzed except for vision, eye motility, and eye blink. This patient was initially taught to communicate using a simple, inexpensive, non-electronic manual scanning matrix communication system. Later, an electronic system was also introduced. A literature review of the electronic and non-electronic ocular controlled communication systems is also included in this article.

BACKGROUND

A 33 year old male sustained a Basilar Artery Thrombosis which left him an akinetic, deaf mute. The only reactions left available to him were vision, eye mobility, and eye blink. A consultation was sent requesting that the occupational therapist establish some form of communication with this patient who was felt to be alert and of normal cognitive ability.

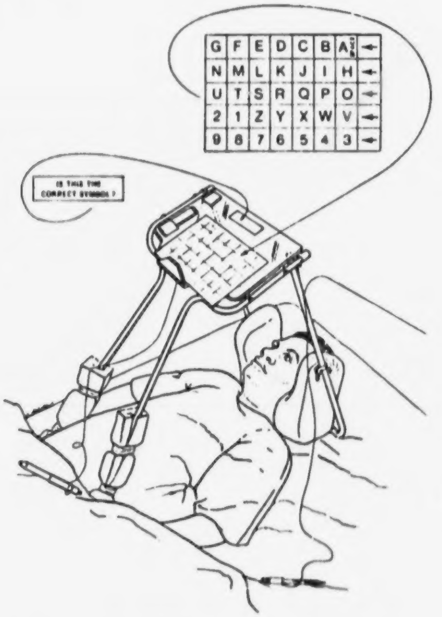
A system was devised consisting of a vertical and horizontal manual scanning communication board, a bed stand, and pen light. The therapist would communicate with the patient through written notes, and responses from the patient required only eye blinks.

DESCRIPTION OF THE DEVICE

A lucite and metal bed reader was purchased and used as a reading stand. This stand was necessary because the patient was usually positioned supine in bed. A similar stand could be made less expensively.

The patient lacked sufficient head control to keep his head from falling to the side. To support the neck and place the head in midline, a headrest was made of foam rubber and stockinette.

A symbol board was made of semiopaque paper. The letters of the alphabet and numbers 1 through 9 appear on both sides of the paper. At the side of each line is an arrow. Above the piece of paper is a box which reads "Is this the correct symbol?". To the left of the box is a slot for a written message. A storage area for blank paper is located below this slot. A pen light and pencil are also included in the device.


G F E D C B A ←
N M L K J I H ←
U T S R Q P O ←
2 1 Z Y X W V ←
9 8 7 6 5 4 3 ←
IS THIS THE CORRECT SYMBOL?

MANUAL SCANNING MATRIX COMMUNICATION SYSTEM USED BY PATIENT WHILE SUPINE IN BED

USE OF THE APPARATUS

The therapist holds a pen light over each arrow rectangle, continuously scanning vertically and in sequence. The supine patient views the letter board from below (see illustration). When vertical scanning reaches the line with the desired symbol, the patient blinks once. The therapist then begins to scan horizontally. When the desired symbol is lit, the patient blinks again.

To verify the selected symbol, the therapist points to the "Is this the correct symbol?" sign. Then the selected symbol is illuminated again, and the patient blinks once for "yes" or twice for "no".

To indicate spaces between words, the patient blinks when the box containing the word "space" is illuminated. Looking up shows that he has finished expressing his sentence or idea.

It took approximately five one-half hour sessions before the patient learned functional use of the device. Within two or three weeks the patient's family and ward staff had learned to use the communication method. The system was used successfully for two months and is still being used.

ALTERNATIVE COMMUNICATION METHODS

After initial communication was established an alternative method of non-electronic eye control communication was attempted. This method, called the Eye Transfer Communication System, or ETRAN, is a portable encoding communicator which utilizes sequential eye gazes for selecting desired messages (1). It consists of a plexiglass square with a center cut out, base for mounting, and stick-on letters and numbers.

Specific problems encountered with the eye transfer system were complexity of instructions; the patient was frequently supine in bed and the board could not be positioned between the patient and the listener to enable continuous establishment of eye contact; it was difficult for the patient to locate desired symbols as placement was unfamiliar to him; coordination and interpretation of eye gazes were difficult; the patient had already become accustomed to the originally taught method of communication.

After eight sessions, the patient was still unable to learn to use the eye gaze system and teaching attempts were discontinued. The patient returned to and is still using the scanning matrix method.

LITERATURE REVIEW

A literature review was done to determine what other eye controlled communication aids were available. Of the non-electronic communication boards, charts, and lap trays, the ETRAN (Eye Transfer Communication System) was the only method requiring only eye control.

Electronic eye-controlled communication aids have been described in an article by Biophysics Group, Applied Physics Department, Delf University of Technology in the Netherlands (2).

One method involves the operation of a switch by looking to the right or left. The switch works with a matrix letter system. Symbols are successively illuminated until the subject stops on the desired one by looking right or left.

With the other method, the patient individually selects the necessary letters by eye fixation upon specifically desired symbols.

Both of the systems described by this group are operated by use of an infrared limbus-pupil-reflection method. The patient wears a pair of photo-transistors with lenses mounted on an eyeglass frame. The device can sense the position of the edges of the iris and the white sclera.

According to the article, few patients have tried the control method and continuous changes are being made to improve the system. Cost is not mentioned, however, there is considerable electronic and mechanical gadgetry.

An ocular controlled eyeglass-mounted communicator is being developed by Rinard and Rugg at the University of Denver Research Institute (3,4,5,6). The device which utilizes corneal reflection is still in the prototype stage with emphasis on clinical use evaluations, methods of encoding, and practical applications.

Similar electronic designs are being developed at other centers (Massachusetts Institute of Technology, Tufts Rehabilitation Engineering Center, and the University of Waterloo, Canada)(7). Anderson (9), and Laefsky (11) also describe ocular control systems in the literature.

An eyeglass mounted ocular control switch was devised for our patient by a U.C.S.D. medical student, Robert Lash. The switch responds to deliberate eye blinks or looking to the right or left. Problems encountered included difficulty positioning the eyeglass frame for optimum operation and ocular fatigue.

Most recently we have been successful utilizing the Prentke Romich Express 1 electronic communication system. A myoelectric control switch uses the Frontalis muscle (eyebrow elevation) contraction to produce a signal. This technique allows the patient to communicate independent of a listener after set-up.

The manual scanning communication board is still being used during times when set-up of the electronic system is not convenient, such as when patient is supine or sidelying in bed. Although it is time consuming to use, we continuously find it to be reliable, easy to set-up and store. It is also relatively simple to instruct family and staff in its use.

REFERENCES

1. Vanderheiden GC, Grilley K. Eds: Non-vocal Communication Resource Book, University Park Press, Baltimore, 1975.

2. ten Kate JH, et al: Eye Controlled Communication Aids. Medical Progress Through Technology. 8:1-21, 1980.

3. Rinard GA, Rugg DE: An Ocular Control Device for Use by the Severely Handicapped. 3rd Conf. of Systems and Devices for the Disabled, Boston 76-79, 1976.

4. Rinard GA, Rugg DE: Communication/Control Applications of the Ocular Transducer. Proc. Workshop on Communication Aids for Handicapped. Nat. Res. Council, Ottawa, Canada. 1977.

5. Rinard GA, Rugg DE: Current State of Development and Testing of An Ocular Control Device. 4th Conf. of Systems and Devices for the Disabled, Seattle, USA. 1977.

6. Rinard GA, Rugg DE: Application of the Ocular Transducer to the ETRAN (1) Communicator. 5th Conf. of Systems and Devices for the Disabled, Houston, USA. 1978.

7. Berg T, Ferdynus R, Green MJ, Petrus T: Eyewriter Prototype I. Department of Systems Design and Electrical Engineering, University of Waterloo, Canada. 1973.

8. Berg T, Ferdynus R, Gree MJ, Kates LK, Petrus T: Construction and Operational Manual for Prototype Eyewriter I. Department of Systems Design and Electrical Engineering, University of Waterloo, Canada, 1973.

9. Anderson KC, Iles GH, Llewellyn-Thomas E: An Eye Position Controlled Typewriter. Digest 11th Int. Conf. Med. Biol. Eng. 29: 410-411, 1976.

10. Rosen MJ: Eye Communicator Under Development. Commun. Outlook 1:3, 1978.

11. Laefsky IM, Roemer RA: A Real Time Control System for CAT and Prosthesis. Behav. Res. Meth. Instr. 192-185, 1978.

APFEL, Eileen, OTR
Occupational Therapy
Rehabilitation Medicine Service
Veterans Administration Medical Center
3350 La Jolla Village Drive
San Diego, CA 92161, USA

6.2

Communication Rate Prediction: Preliminary Studies

Laura A. Demsetz, Massachusetts Institute of Technology
Michael J. Rosen, Ph.D., Massachusetts Institute of Technology
Cheryl Goodenough-Trepagnier, Ph.D., Tufts-New England Medical Center

ABSTRACT

Development of a computer-based system for selection of the best non-vocal communication device for each potential user is in progress. An important criterion for device selection is communication rate, which is a function of the user/device system. A method for predicting communication rate without resorting to device-by-device testing is reviewed. Critical to the success of this method is the ability to estimate the time it takes a potential user to make any movement required to operate any device. Presented here are results of a preliminary investigation into the feasibility of obtaining such an estimate from a target acquisition test in which only a subset of all possible movements are tested. Data was obtained from a videotape of an experienced user of an Autocom. Randomly selected subsets of movements were used to estimate the time required for the entire set of movements. For this data set, a relatively small subset of movements gave a very good estimate of the total time required.

INTRODUCTION

Background

Conditions such as cerebral palsy, Parkinson's disease, multiple sclerosis, amyotrophic lateral sclerosis, or head injury can cause a loss of the motor control required both for speech and the effective use of a standard typewriter. A wide variety of specialized non-vocal communication devices (NVCD's) exist, with interfaces designed to take advantage of any remaining motor abilities. The clinician is faced with the multi-dimensional task of selecting the most appropriate device for a particular patient. Ensuring that the best existing device is actually selected may be quite difficult, particularly if the clinician has not had much exposure to the many different types of devices, or if only a few devices are available for trial use.

Under a project funded by the N.I.N.C.D.S., a joint Tufts New England Medical Center/Massachusetts Institute of Technology research team headed by Dr. Cheryl Goodenough-Trepagnier and Dr. Michael Rosen is developing a computer-based system for NVCD prescription. Based on a set of importance ratings determined by consultation with experts in the field, a comparison is made between the patient's needs and abilities and a device's features and operational requirements, respectively. The device with features that best satisfy the patient's needs while requiring for operation a minimum of the abilities possessed by the patient is selected as the best device.

Device features and operational requirements are, with the exception noted below, patient-independent and can be established and catalogued in the laboratory. Thus, the range of devices under consideration is not limited by a particular clinician's personal experience or to devices on hand. After following the protocol for determining a patient's needs and abilities, the clinician, using a computer-assisted comparison proceedure which weights the relative importance of each factor, can select the best device for the patient.

A fundamemtal goal in selecting a NVCD is to increase communication rate. However, rate can neither be tabulated as a device feature, nor evaluated as a user ability. It is, rather, a function of the "man-machine system", and will be different for each user/device combination. Unless communication rate can be predicted based on some combination of previously determined device features and testable user abilities, literal device by device testing will be required. This type of trial and error prescription is frustrating, time-consuming, and requires the availability of an example of each device under consideration, defeating the purpose of the prescription proceedure.

Communication rate calculation

The framework for predicting communication rate from independently determined device features and user abilities has been presented by Rosen and Goodenough-Trepagnier (1). Communication rate is considered a function of three factors: the specific inventory of language units from which text is constructed, the mapping of these units onto the device interface (i.e. the sequence of movements required to select each unit), and the time the user requires to make each movement.

By decomposing a large body of text or sample of speech according to the set of language units used, the frequency of occurance of each unit and each pair of units (digram), can be determined. Knowing, in addition, the movement sequence required to select each unit, and the time required to make each movement allows calculation of communication rate:

$$\mathrm{RATE} = \frac{1}{\Sigma(\mathrm{freq}_u)(\mathrm{time}_u) + \Sigma(\mathrm{freq}_d)(\mathrm{time}_d)}$$

where freq_u = unit occurance frequency
freq_d = digram occurance frequency
time_u = unit selection time
freq_d = digram selection time

The unit and digram frequencies are determined by the particular language unit inventory used, and as such (assuming roughly consistent usage of language over all users (2)) are features of the specific device under consideration. The selection times, however, depend both on the device interface layout and on the user's motor abilities. Since each device's interface layout is known a priori, what remains is to obtain a complete enough characterization of a user's movement ability to estimate the time necessary to make any movement required by any device.

Several closed form models of the relationship between speed, extent, and accuracy of movement have been proposed (see, for example, (3), (4),(5)). However, the applicability of these models to the disability groups under consideration has not been examined. Therefore, a motor ability assessment task of sufficient detail to provide movement time data for the entire workspace under consideration will be included in the user ability assessment protocol. Initially, this task will be limited to evaluation of pointing movements made in a plane, as would be required by a lapboard or a custom or standard flat keyboard. A computer-controlled testing board composed of a 24" x 24" touch sensitive transparent screen mounted above a similarly sized array of LED's has been designed to allow convenient control of target display and accurate recording of point to point movement times.

The task of testing exhaustively all movements in the 24" x 24" workspace is overwhelming. For example, if only targets of 1" x 1" are considered there are over 300,000 distinct movements to be tested. Clearly only a subset of these movements could be tested in a testing session of reasonable length in which some check was made on repeatability. Prior to implementation of the target display board, a preliminary test was conducted to provide an estimate of how accurate a prediction of communication rate could be provided by such a subset, and to investigate the effects of choosing different subsets.

MATERIALS AND METHODS

As a source of data, a videotape was made of an experienced NVCD user communicating using an Autocom from a wheelchair. The subject, age 37, is unable to communicate adequately verbally due to athecoid cerebral palsy. He has been using some type of NVCD for 25 years, and, at the time of the test, had been using this particular device for approximately six months. The conversation recorded on videotape was a two hour interview with physical and occupational therapists at Tufts New England Medical Center as a part of the development of the patient evaluation protocol mentioned above. The analysis below includes only those sequences in which the subject did not appear to be distracted by questions or background conversation.

The video camera was located approximately 5' in front of the front edge of the Autocom at a height of approximately 4' above the level of the Autocom. The upper half of the subject's body, the entire surface of the Autocom, and a digital timer were clearly visible throughout the session. The switches on the Autocom are activated by means of a magnet worn on a ring. The switches are arranged on 1" centers in an 8" x 16" array. Resolution on the videotape was such that the borders of the individual switch areas were clearly visible, and the timer readable to 0.1 seconds.

As noted above, only those movements made while the subject appeared undistracted were recorded. This yielded 863 point-to-point movements. The aggregate time required to make these movements was 2549 seconds.

RESULTS AND ANALYSIS

A plot of movement time vs. length of movement for the entire data set is shown in Fig. 1. To investigate the ability of a subset of data to predict communication rate over a larger set, ten samples at each of seven sample sizes (ranging from 1% to 11.6% of the total population) were selected at random from the entire body of data. For each sample, a least squares fit was used to obtain a linear relationship expressing movement time as a function of length of movement. Using this relationship, a prediction of the time required to make each of the 863 movements in the complete data set was obtained. These times were summed, and the percentage error between this predicted total time and the actual total time (2549 seconds) was found. The averages of the percentage errors over the 10 random samples for each sample size are plotted as a function of sample size in Fig. 2. A one sided Student's t test was used to establish a 95% confidence maximum error value, also shown in Fig. 2.

DISCUSSION

For this set of data, it appears that a randomly selected subset comprised of as little as six percent of the entire population provides a good prediction of total time (7% error at a 95% confidence level). This is encouraging, as it indicates that good estimates of communication rate may in fact be obtainable from a relatively short testing session.

Further analysis of this preliminary data is underway to determine if even better predictions can be obtained by treating the entire population of movements as several smaller more homogeneous populations--for example, separating the data into subpopulations by the location of the initial point or by the direction of movement. The characteristics of each subpopulation could then be estimated from a random subset as above.

It should be noted that the present data represents only one observation of a subject who is experienced at making the type of movements required. Further testing will be done (using the target acquisition board described above) to determine if similar results are found in the same subject over a period of time, and what results are obtained with other less experienced users. In addition, control tests will be conducted to determine if there is a significant difference between movements initiated by the user and movements required in a target acquisition task.

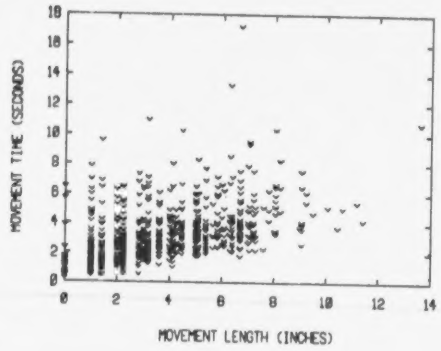


Fig. 1 Movement Data from Videotape

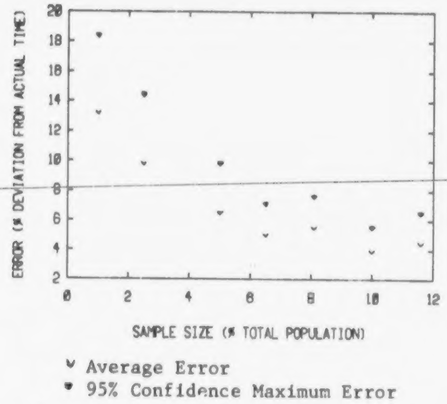


Fig. 2 Variation of Error with Sample Size

REFERENCES

1.Goodenough-Trepagnier, C., Rosen, M., Demsetz, L. "Determinants of Rate in Communication Aids for the Non-vocal Motor Handicapped," Proceedings of the Human Factors Society 26th Annual Meeting, October, 1982, 172-275.

2.Beukelman, D.R., and Yorkston, K.M.,"Communication Interaction of Adult Communication Augmentation System Use," Topics in Language Disorders, March, 1982, 39-53.

3.Fitts, P., "The Information Capacity of the Human Motor System in Controlling the Amplitude of Movement," J. Exp. Psych., 1954, 47, 381-391.

4.Kvalseth, T.O.,"The Power Law of Motor Control: Some Diverse Applications," Proceedings of the Human Factors Society 26th Annual Meeting, October, 1982, 339-343.

5.Howarth, C.I., Beggs, W.D.A., and Bouden, J.M. "The Relationship Between Speed and Accuracy of Movement Aimed at a Target," Acta Psych., 1971, 35, 207-218.

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6.3

THE CONTROL EVALUATOR AND TRAINING KIT: AN ASSESSMENT TOOL FOR COMPARATIVE TESTING OF CONTROLS TO OPERATE ASSISTIVE DEVICES

Margaret R. Barker, William R. Hastings and Kelly Flanagan
Children's Hospital at Stanford, Rehabilitation Engineering Center
Palo Alto, California

ABSTRACT

The Children's Hospital at Stanford (CH@S) has developed the Control Evaluator and Training Kit (CETK). It is a portable, microprocessor-based device used as a tool for systematic, quantitative assessment and training for using controls with assistive devices. This tool is used to collect information regarding a disabled person's ability to control assistive devices used for mobility, communication and environmental control. The CETK is described as well as a methodology that is currently being used to field test this device in clinical settings outside of the Rehabilitation Engineering Center (REC).

INTRODUCTION

A systematic approach is necessary to select an appropriate control that can be used by an individual with disabilities to use an assistive device. There are three major steps in selecting a control: 1) control site selection (identification of controllable anatomic sites), 2) control selection (controls that can be used by the control sites identified in step 1), and 3) the comparative testing of the control site control combinations (1, 2). The CETK is a tool used during this systematic evaluation to identify operable controls. It will assist with the selection of a control and identification of the position of a control in a workspace. It is used to collect quantitative information for comparison of the control site/control combinations and some of the control strategies.

DESCRIPTION

The CETK (Figure 1) consists of a display, a set of controls and a control panel (Figure 2). The type of control to be used, the type of output and the desired tasks and measurements are selected from the control panel.

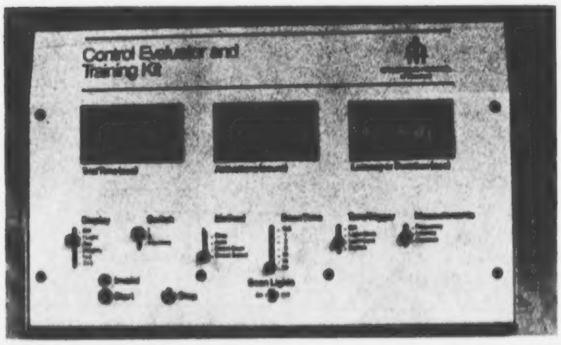

Figure 2. Control panel for selection of desired tasks and measurements

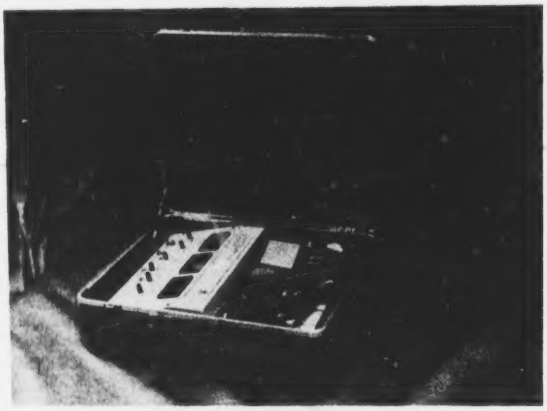

Figure 1. The Control Evaluator and Training Kit

The controls that can be used with the CETK are grouped into four categories: single switches, switch arrays, joysticks and small keyboards. Controls included in the CETK are the Zygo Switch Kit, an Atari Joystick, a small membrane keyboard and a small pushbutton keyboard. Other controls can be used with appropriate adapters.

The outputs provided by the CETK can be visual, auditory and/or an external device. The visual output consists of using one, two, three or nine of the elements of a 3x3 matrix of incandescent lights. When using direct selection, as with a keyboard or joystick, or scanning with a single switch, all nine elements can be used. Three elements can be used for a linear scan. Two elements can be used with two switches for displaying choices using two switches. One element is used with tasks involving one switch.

An additional visual feedback to the examiner and or the client that can be used during an evaluation are the ten LEDs (scan lights) placed horizontally across the top of the display. When using a scanning method, the incandescent lights will remain on for the duration of the scan time selected from the control panel. Also during this period of time, all ten of the LEDs will sequentially illuminate. These LEDs are used to provide additional information regarding control use and strategies. For example, they can be used with a scanning task using the 3x3 array of lights to find out how long it took the client to make the selection. The time that it took the client to make a selection during the scanning task, is the number of the LED that is lit (1 to 10) multiplied by .1 (each LED is sequentially illuminated for .1 of the period designated by scan rate) and by the scan rate selected from the control panel (.5 to 20 sec/element).

The auditory output can be triggered by either activation of a control or triggered by the output. The auditory output can be either a beep or continue as long as the switch is activated or for the duration of a designated output. The auditory output has an adjustable volume and frequency. The tone can be checked by the examiner prior to a trial with the client.

The third output is an auxillary output which consists of a minimicrophone jack on the face of the display which allows the evaluation of control using motivatiing devices such as toys.

The methods of selection using the controls in this device allow for direct selection and scanning. Direct selection is used with the keyboards, joysticks, switch arrays and the single switches. Scanning can be done with either a single switch, a joystick or a switch array.

DEVICE OPERATION

Prior to using the CETK the client must be properly positioned and seated. Range, resolution, and functional skills of potential control sites should be analyzed in order to determine a set of possible controls for each control site. The CETK is then used to provide feedback when a control is activated and to quantitatively compare the control site/control combinations.

Quantitative evaluation is necessary to compare control site/control combinations identified during an initial evaluation to develop a list of controls, rank-ordered according to optimal use by the client. The measures include the client's speed and accuracy in activating the control, the degree to which the performance with a control can be repeated over time, i.e., from week to week (1,2).

The measurements that are monitored with the CETK are trial time, frequency (activations/sec), latency (reaction time to either release or activate a switch), duration (length of activation) and performance errors. These measurements are used to collect data regarding speed, accuracy, fatigue and repeatability (Table 1).

Based on the performance measurements from Table 1, each of the control site/control combinations initially determined to be potentially useful are rank-ordered. This list should be referred to when matching the client's abilities and needs to device characteristics (3) It is necessary to specify more than one control and rank these according to usefulness. This is particularly important in that sometimes the "best" control will not be functional when used with a given system. From this list, the user and the examiner may select according to the device to be operated, and not least of course, according to the user's preference based on experience with the control using the CETK.

parameters controls	speed: track time	speed: select time	accuracy	fatigue	repeatability
Keyboard	-latency to activation	-frequency during specified task -latency to release	-errors during specified task	-measures of speed and accuracy at beginning and end of session -subjective evaluation of client	-measures of speed, accuracy and fatigue between sessions
Joystick/ Switch Arrays	same as above	same as above	-duration in a specified direction or of a switch closure for a specified period of time -errors during specified task	same as above	same as above
Single Switch	same as above	same as above	-duration for specified time	same as above	same as above

Table 1. Measures to quantify those parameters related to the overall usefulness of control site/control combinations.

CLINICAL EVALUATION

Clinical evaluation or a field trial has been cited as a necessary step in the design process of the research and development of prototype devices (4,5,6,7). The third prototype of the CETK is complete and five units will undergo clinical evaluation. Accordingly, each of the CETKs are being disseminated to outside clinical settings and will undergo objective and subjective evaluation by each of the clinical evaluation sites.

The objective evaluation is composed of three steps as follows: (1) user training at each site through explanation and demonstration of the CETK by the Rehabilitation Engineering Center clinical evaluation team, followed by supervised use of the device in a role-playing situation with an able-bodied partner; (2) quantitative assessment of five disabled clients at each site using the CETK; and (3) completion of a formal evaluation questionnaire. Subjective feedback will be elicited from the clinical evaluation sites as a group for the collection of any data or information not included in the objective individual site evaluations.

The results of the clinical evaluation will be used to determine if any redesign is necessary and market potential and will be disseminated to potential manufacturers of the CETK.

DISCUSSION

The Control Evaluator and Training Kit is designed to provide to the professional community working with disabled individualls a tool to evaluate and train for control of assistive devices. Used with the publication A Guide to Controls: Selection, Mounting, Applications, decisions could be made regarding a person's ability to use standard controls and whether specialized help would be needed to identify an appropriate control. This would help reduce cost and travel time to specialized centers for those clients able to use standard controls. The specialized centers would then be able to devote more time to the most difficult cases that require modifications or specialized controls, and to research and development.

ACKNOWLEDGEMENTS

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REFERENCES

1) Barker, M.R. and A.M. Cook, "A Systematic Approach to Evaluating Physical Ability for Control of Assistive Devices", Proceedings of the Fourth Annual Rehabilitation Engineering Conference, Washington, D.C., 1981.

2) Cook, A.M. and M. R. Barker, "A Systematic Approach to Choosing Interfaces for Assistive Devices". Submitted for publication, 1982.

3) Coleman, C.L., A.M. Cook and L.S. Meyers, "Assessing Non-Oral Clients for Assistive Communication Systems", J. Speech and Hearing Disorders, 1980. 45: 515-526.

4) Kohn, J., S. Enders, J. Preston, Jr. and W. Motloch. Provision of Mobility Postural Assistive Devices, Rehabilitation Engineering Center, Children's Hospital at Stanford, 1980.

5) Platt, P.H. and D. A. Hobson, "A Proposed Methodology for Rehabilitation Engineering Decision-Making", Proceedings of Interna- Conference on Rehabilitation Engineering, Toronto, 1980.

6) Levy, R., K. Waksvik, and P. Nelson, "A Clinical Evaluation Procedure for Communication Equipment for the Speech Impaired - A Case Study, with Recommendations, on the Blissterm and M.C.C.S.", Proceedings of the Fourth Annual Rehabilitation Engineering Conference, Washington, D.C., 1982.

7) Coleman, C. L., Ph.D, A. M. Cook, Ph.D., and L. Meyers, Ph.D., Final Report Submitted to Department of Education for Field Initiated Research Project Enhancing the Education Potential of Non-Oral Children Through the Matching Communication Device Capabilities to Children's Needs, Grant No. G007902261, CFDA #13, 443c, 1982.

6.4

TOWARD THE CONVEYANCE OF DEAF SIGN LANGUAGE OVER PUBLIC TELEPHONE NETWORKS

T.P. Sosnowski and To R. Hsing
GTE Laboratories Incorporated
40 Sylvan Road, Waltham, MA 02254

Abstract

This work explores the possibility of transmitting deaf sign language over low bandwidth telephone lines in real time. Techniques including image processing and picture coding, spatial/temporal resolution reduction are applied to images of a deaf person signing. Specialized hardware has been designed and constructed which allows the resolution of images to be selectively degraded in space (fewer picture elements per image) and time (reduced frame rate). Using the hardware, a series of psycho-physical experiments were conducted to determine the minimum image quality required to convey meaning in handsign language as used by the deaf.

Introduction

Telephone service - pervasive, inexpensive, reliable - a communication resource of such utility that modern society is inconceivable without it. Yet large numbers of people cannot effectively use the telephone for they are unable to sense the sound which the system conveys. Because of their particular physical affliction, the deaf are largely isolated, not only from society as a whole, but, as well, from other members of the deaf community with whom they normally seek interaction. One solution to this communication problem which has received widespread attention is the teletypewriter or terminal device for the deaf (TDD). Unfortunately, many within the deaf community are insufficiently literate to create the written text these machines require. Sign language (1) is commonly used by the deaf to communicate. Being a gestural-visual mode of communication, electronic transmission of the language would normally require wide bandwidth video connections to convey the television-like moving images in real time. Such wide bandwidth links are neither low cost nor widely available.

Experiments to determine minimum resolution required to convey deaf sign language have been conducted by Sperling (2) and Pearson (3). The former concluded that a minimum bandwidth of 21 kHz was required. The latter observed that comfortable communications occurred at 100 kb/s data rates, exchange of information remained possible to 5 kb/s. Tarttler and Knowleton (4), in a novel experiment, studied the perception of sign features from an array of spots strategically located on the signer's hands. The ability to correctly interpret a message by observing only the trajectory of spots on the display suggested a very low information transfer rate.

Data Rates For Image Display

From the standpoint of minimizing ultimate system cost, it is reasonable to capitalize on existing broadcast format television cameras and receivers. A standard monochrome television receiver utilizing analog techniques requires a bandwidth of about 4 MHz; comparing this to the 4 kHz bandwidth of telephone circuits indicates the magnitude of our problem: we must reduce the analog bandwidth by a factor of a thousand. Since we propose to use digital signal processing techniques to reduce the data content of the required images, we will review, from this viewpoint, the standard NTSC television signal. Thirty images or frames are transmitted every second; a frame consists of 480 scan lines, each of which contains 320 discrete picture elements (pels). A monochrome representation allows a pel to take on one of 256 intensities (requiring eight bits/pel to specify). Thus transmission of a standard TV picture requires a data rate of about 40 Mb/s. The transmission of a single television image at the 9.6 kb/s data rate available over telephone lines would thus require more than two minutes - clearly unacceptable for meaningful sign language communication. A reduction in the data rate by a factor of 4000 is required for a viable system.

Static Experiments

Several options are available to us to effect this reduction. These can be divided into two principal classes: resolution reduction and image compression techniques. The latter attempts to advantageously use redundancy in images to reduce data. The former, resolution reduction, has three aspects with which we can tamper: gray scale, temporal (frame rate) and spatial (number of pels) resolution. The utility of various combinations of these items has been the subject of our investigations; we have attempted to determine the minimum image resolution necessary to convey meaning in handsigning.

Our early studies were conducted with the aid of a computer based image processing facility. The nature of the system allowed the manipulation of still images only, however it provided us with insights into minimum resolutions which were utilized in subsequent dynamic experiments. A representative TV resolution full gray scale test image is depicted in Figure 1. Handsigning is a complex and well developed language, operating in three-dimensional space; often differences in mean are conveyed by subtle body language which could be difficult to capture with low resolution images. Nevertheless, in our early studies we were interested in preserving only hand and mouth shape information.

One of the most immediate bit savings in an image can be gained by decreasing gray scale resolution. The ultimate reduction occurs when a pel is characterized by a single bit; that is, it is assumed to be either white or black depending on whether its original intensity level (one/256 possible) is above or below some arbitrary value called a threshold. Shifting the threshold up or down can profoundly alter the perceived information content of the black-white or bi-level image. An optimum value depends upon several factors

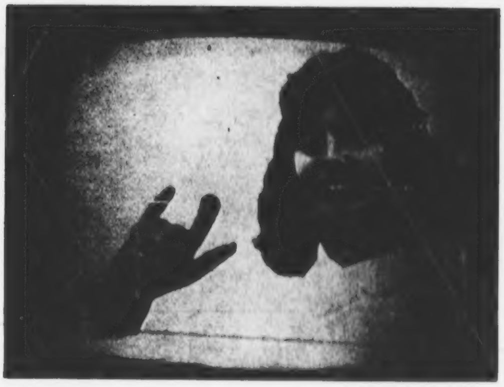

Figure 1. The original version of test image

including lighting conditions, color of clothes and even the hair style of the signer. While automatic strategies are available to so segment an image, expediency dictated a trial and error selection process in this experiment. The bi-level images seemed to adequately convey the vital hand and lip shape information deemed necessary here.

The second course of action addressed the reduction in spatial resolution. For example, we achieve a bit savings of n^2:1 by transmitting only the picture elements 1, n+1, 2n+1, 3n+1 ... along a line, and similarly only scan lines 1, n+1, 2n+1, 3n+1 ... of the picture. At the receiver, the full size of the picture is recovered by repeating each received pel or line n-1 times. Naturally, the resulting image quality is degraded. Figure 2 is a bi-level version of Figure 1 with the spatial resolution reduced by 64:1. Note that hand and lip shape information is preserved in this example.

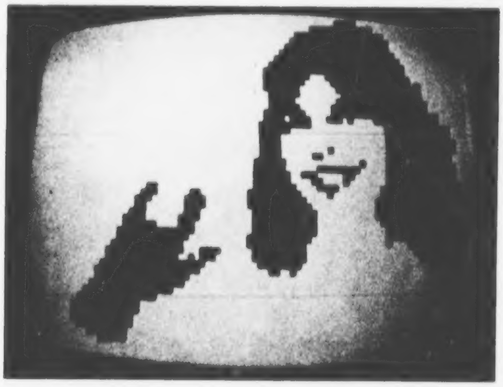

Figure 2. The binary version of spatial resolution reduction with 64:1 compression ratio

The computer processing facility was also useful in the study of image coding techniques. This effort attempts to exploit the redundancy typically found in images to reduce the data necessary for their characterization. Similar studies have been conducted in conjunction with efforts to reduce the document transmission time required by facsimile systems (5). Facsimile requires the transmission of high resolution (200 lines per inch) imagery, and coding efficiencies of the order of ten are routinely attained. High resolution images appear more amenable to greater coding efficiency. With our low resolution images, the number we have been able to obtain, under the best of circumstances, can best be described as modest; factors of 3:1 on a 60x60 element image appear maximum, 2:1 more reasonably attainable.

Considering the reductions of 64:1 resolution, 8:1 in gray scale, and 2:1 for image coding provides us with a total factor of 1000 in reduction of the data rate.

Dynamic Experiments

The studies described thus far have all been carried out with the aid of computer simulations; thus the image processing could not be conducted in real time. Further, although we can view the closely controlled static images and maintain that the reduced resolution appears sufficient, only an actual test in which deaf subjects "converse" through such images can the utility be verified. In order to gain further insight into the viability of the reduced resolution images, specific hardware (the degrader) was designed which would allow the spatial and temporal resolution of bi-level moving TV images to be degraded. The frame rate could be slowed by factors of 1:1 through 1:15 and the spatial resolution by a factor of 1^2:1 through 8^2:1. The input to the degrader was a standard monochrome TV camera signal, the output was connected directly to a baseband TV receiver. The degrader was designed to allow the horizontal and vertical resolution to be controlled independently (while maintaining the original image size), however the horizontal resolution controller was inoperable at the time of the test, therefore only the vertical resolution and the frame rate were reduced in the experiments.

A series of 50 "sentences" containing commonly used signs was compiled by a person skilled in sign language. This same person subsequently served as the signer in front of the TV camera. Six deaf persons, each highly skilled signers, were used as subjects. The experiment was broken down into a series of 24 tests, each containing a particular combination of spatial and temporal resolution. For each test, a deaf subject was presented with a randomly selected subgroup of ten sentences from the original 50. The number currently recognized was determined to be a measure of the utility of that resolution combination. Before actually running the experiment, each subject was allowed 20 minutes to become acclimated to the machine and its various image qualities. Nevertheless experimental evidence demonstrates improved recognition with increased use. Some of the subjects viewed the lowest quality images first, others the highest quality first. In at least one case, a subject scored a higher recognition rate with lower quality images. The graph of the experimental results are shown in Figure 3. Note the falloff in recognition at the low frame rates. Surprisingly, however, is the relatively good recognition, even at eight frames per second.

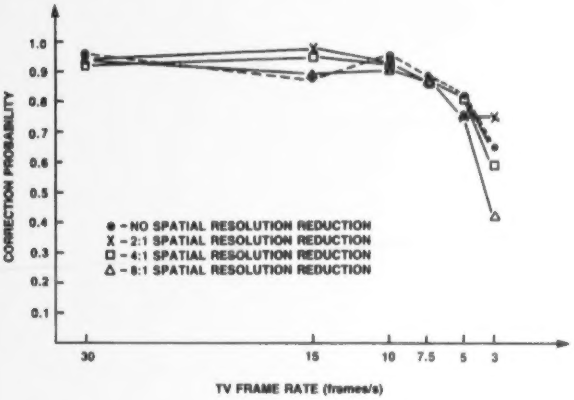

Figure 3. Correction probability versus TV frame rate at different spatial resolution reduction

Recall that TV image data must be reduced by a factor of 4000 to allow transmission over telephone line, and that a factor of 1000 may be attained through factors described previously. The frame rate reduction to eight per second may provide the additional factor of four required.

Conclusion

We have demonstrated that the data rate required for standard monochrome TV images must be reduced by a factor of 4000 in order to allow their transmission over telephone lines in real time. We have investigated various factors which could allow the transmission of deaf sign language over telephone lines. We have obtained a factor of eight reduction by eliminating gray scale imagery, a factor of 64 by reducing spatial resolution, a factor of two by redundancy coding and a factor of four by reducing the frame rate. The total provides the required factor of 4000. It yet remains to tie all of these factors into one system to determine the ultimate viability of the scheme.

References

1. C. Baker and D. Cokely, American Sign Language, T.J. Publishers, Inc., Silver Spring, MD, 1980.

2. George Sperling, "Video Transmission of American Sign Language and Finger Spelling: Present and Projected Bandwidth Requirements," IEEE Trans. on Communications, Vol. COM-29, No. 12, December 1981.

3. Don Pearson, "Visual Communication Systems for the Deaf," IEEE Trans. on Communications, Vol. COM-29, No. 12, December 1981.

4. V. Tarttler and K. Knowlton, "Perception of Sign Language From An Array of 27 Moving Spots," Nature, Vol. 289, February 19, 1981.

5. R. Hunter and A. Robinson, "International Digital Facsimile Coding Standards," Proceedings of the IEEE, Vol. 68, No. 7, July 1980.

T. P. Sosnowski
GTE Laboratories Incorporated
40 Sylvan Road
Waltham, MA 02254

ADAPTIVE DICTIONARY FOR COMPUTER-BASED COMMUNICATION AIDS

C. D. Gibler[1] D. S. Childress

Northwestern University Rehabilitation Engineering Program

ABSTRACT

A dictionary is described that matches a high percentage of general user vocabulary. It consists of a fixed (core) element of frequently used words, and a learning element that adapts to the topic of the text.

The purpose of the dictionary is to provide a more efficient means of English text generation than letter selection for individuals with severe motor impairments. Simulation data is presented that demonstrates an improvement in efficiency (measured in number of inputs per letter) for scanning communication aids with the addition of the dictionary. Lexical criteria that assisted in the choices of sample texts for the simulations are also discussed.

INTRODUCTION

The scanning communication aid is primarily designed for the individual whose disability permits only one or two controlled inputs. Because of the limited number of inputs, letters and words must be presented sequentially, often requiring several inputs for each language unit selected. A scanning aid can thus be characterized by the average number of user inputs per letter to generate text. This measurement, termed text generation efficiency, is a parameter addressed by anticipatory techniques.

One approach of anticipatory methods is to improve text generation efficiency by using statistical information about the English language to predict what letter the individual needs, given his previous selections. The improvement in text generation efficiency is achieved by a dynamic rearrangement of the aid's language contents, such that most probable letters can be accessed first by the user.

Text generation rates with anticipatory aids are still slow when compared with writing speeds for nondisabled individuals of 20 to 25 words per minute (1). From the work of Foulds et al (2) and the language entropy calculations of Shannon (3), it does not appear that these speeds can be significantly improved with language elements confined to letters of the alphabet.

As anticipatory schemes for letter selection have reached a mature stage of development, an additional set of language units must be established to increase the fluency (4) of a scanning aid. A dictionary of commonly used words seems a natural next approach, because language output from an aid would remain in the form of English text.

CHARACTERISTICS OF ENGLISH

Before attempting the construction of a dictionary, one needs to have an understanding of the lexical makeup of language. A few terms are first defined (from Smith (5) and Kucera (6)).

- A token, or individual word, is defined as a continuous string of graphemes, uninterrupted by space.
- A type is defined as a set of identical individual tokens.
- X represents the frequency of occurrence of a type.
- Fx represents the number of types of a given frequency, X.
- Hapax legomena is the set of types occurring only once in a sample (X=1).

Several general statements can be made about any American-English text containing N words (tokens) and a vocabulary of V types. First, vocabulary size V increases more slowly than text size N, but V never asymptotes. Second, a very small percentage of high frequency types accounts for a large proportion of the text. Finally, hapax legomena always constitute the largest frequency class. However, as N increases, the cumulative proportion of hapax legomena decreases. A typical sample text word distribution is shown in Figure 1.

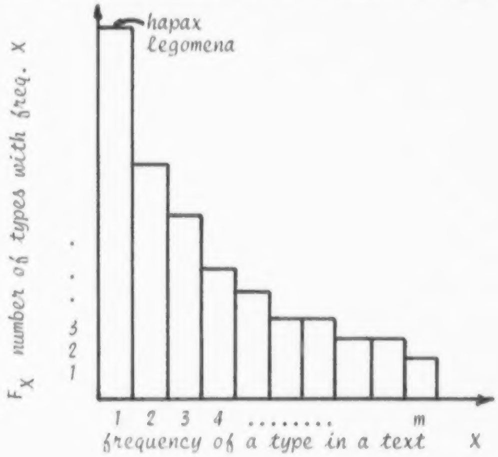

Fig. 1. Typical word frequency distribution of sample text.

A number of lexical measures have been devised to provide a more quantitative approach to text analysis, including the logarithmic type/token ratio (8), Yule's K statistic (9), and Kucera's lexical measure L (6).

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[1] Now with Bell Laboratories, Naperville, IL

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$$\underline{L} = \underline{D}/\log \underline{N}$$

where $\underline{D} = -\sum_{\underline{V}} p(i)\log p(i)$, and $p(i) = Fi/\underline{N}$

In terms of word frequency distributions,

$$\underline{D} = -\sum_{X} Fx(X/\underline{N})\log(X/\underline{N})$$

If all words in a sample occur only once (all belong to hapax legomena), then

$$\underline{D} = -\sum_{X} Fx(1/\underline{N})\log(1/\underline{N}) = \log \underline{N}$$

Kucera uses $\underline{L}$ as a relative indicator of textural connectivity. A high degree of $\underline{L}$ implies a sample containing many different topics; whereas, a low value of $\underline{L}$ suggests a sample containing a single specialized topic. $\underline{L}$ is more sensitive to sample size than $\log \underline{V}/\log \underline{N}$, but provides additional information about the word frequency distribution of the sample.

Kucera applied this and other measures to a subset of the Brown Corpus (10) containing approximately 100,000 words, divided into 50 samples of 2000 words from 14 different literary genres. Based on his analysis, several criteria were chosen to guide the selection of sample texts for evaluating the lexical contents of communication aids. We consider a 2000-word sample of American-English text to be representative of typical written American-English discourse if it meets the following lexical criteria (based on Kucera's empirical findings):

1. $0.05\ \underline{N} \le$ hapax legomena $\le 0.40\ \underline{N}$
2. $0.85 \le \log \underline{V}/\log \underline{N} \le 0.90$
3. $0.73 \le \underline{L} \le 0.78$

A fair evaluation of the impact of a dictionary on text generation rate and efficiency demands judicious selection of text samples, and these criteria form a sound linguistic basis for that selection process.

DICTIONARY DESIGN

The contents of a dictionary must account for a high percentage of the vocabulary of a text to make word selection useful. To ensure a high percentage match, a two-component dictionary proves effective. We selected the following components:

* Core element - A core group of the 1000 most frequently occurring word in American-English text beginning with a two letter digram (taken from the one million word Brown Corpus (10)).
* Learning element - This adaptive feature allows the dictionary to dynamically configure itself to the vocabuary needs of the user and topic. New words typed into the communication aid are automatically added to the dictionary for future use.

SOME PRACTICAL CONSIDERATIONS

Having established the desired structure of the dictionary, storage and access mechanisms were examined. The dictionary was implemented in PASCAL with a personal computer (the Apple II+). Words in the core element were truncated to a maximum of ten letters, which affected less than 40 of the 1000 most frequently used words. A 200-word learning element reserved storage for 16 letter words. The combined 1200 word dictionary resided in 13.2K bytes of memory.

During text generation associated with the study, new words were stored in a chronological fashion until the 200 string array was filled, at which point the algorithm wrapped around to the beginning of the array to replace oldest entries first.

A review of the literature in computational linguistics and artificial intelligence revealed that no straightforward method existed to access the dictionary on the basis of syntactic or semantic information, particularly when limited to small processor applications (12). As a result, an alphabetic access mechanism was implemented. That is, the user first selects the initial two letters of each word from a digram-based anticipatory display adjacent to the text. Once the first two letters are selected, the computer searches through the dictionary and displays (in a vertical list) sequential groups of, at most, eight words beginning with that initial digram. The user then simply scans down the list to select the desired word. (A more detailed description of a similar algorithm is presented in (13).) The index arrays needed to quickly access the dictionary require 4K bytes of storage, yielding a total dictionary size of 18K bytes for the prototype design, well within the capacity of the personal computer.

MEASUREMENTS OF TEXT GENERATION EFFICIENCY

The dictionary was imbedded in a simulation of a two-input, digram-based anticipatory scanning aid to measure the impact of word selection on text generation efficiency. Three sample texts were randomly chosen from 2000-word segments of newspaper articles on children's rights, U.S.-Soviet relations, and the discovery of the structure of DNA. All samples satisified the previously stated lexical criteria. Each text generation simulation started with the 1000-word core element and a cleared learning element.

For the three samples, the core element alone matched 54% to 69% of the words in the text, with a text generation efficiency ranging from 3.46 to 3.16 user inputs per letter. The core plus learning element matched from 71% to 76% of the words, with a text generation efficiency of 2.99 to 2.87 inputs per letter. This is compared to a text generation efficiency range of 3.91 to 3.86 inputs per letter for digram letter selection alone. Therefore, the addition of the dictionary resulted in an average decrease of one input per letter for widely varying topics, or about a 24% improvement in text generation efficiency.

Smaller samples of text were also examined by simulation to determine if the dictionary still had a positive effect. A 375-word text taken from a rehabilitation journal was evaluated from the perspective of core element size, core element alone versus core plus learning elements, and digram versus monogram letter selection. The results are shown in Figure 2, and illustrate a number of points. To begin with, digram letter selection is always more efficient than monograms, and that the difference is significant. In the same way, the core plus learning elements are always superior to a fixed-core element. Finally, increases in the size of the core element did not significantly affect text generation efficiency after 500 words, suggesting that a smaller core element is feasible. These trends were consistent for all text samples examined.

CONCLUSIONS

A dictionary was designed based on current knowledge about the lexical characteristics of written American-English. The dictionary was shown to reduce by 24% the average number of user inputs per letter during text generation when accessed via a digram-based alphabetic search procedure. These results were obtained with a prototype two-input, scanning communication aid designed around a personal computer. However, the dictionary may also be used advantageously in direct selection aids for individuals with slow pointing motions. In addition, lexical criteria were established from empirical findings in linguistics that provide guidelines for sample texts to be used in the evaluation of communication aid effectiveness.

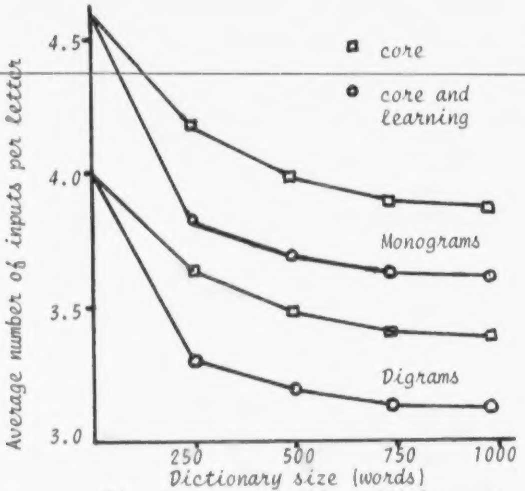

Fig. 2. Communication efficiency as a function of dictionary size as computed in transcription of a 375-word sample text.

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REFERENCES

1. Chapanis, A., Ochsman, R., Parrish, R., and Weeks, G., "Studies in Interactive Communication Modes on the Behavior of Teams During Cooperative Problem Solving", Human Factors, 14, 1972, pp. 487-509.
2. Foulds, R., Baletsa, G., and Crochetiere, W., "The Effectiveness of Language Redundancy in Non-Verbal Communication", Pro. of Conf. on Devices and Systems for the Disabled, Philadelphia, 1975, pp. 82-86.
3. Shannon, C., "Prediction and Entropy of Printed English", The Bell System Technical Journal, 30, 1951, pp. 50-64.
4. Eulenberg, J., Reid, R., and Rahimi, M., "Representation of Language Space in Speech Prostheses", Proc. of 4th Ann. Conf. on Systems and Devices for the Disabled, Seattle, 1977, pp. 109-114.
5. Smith, R., "Probabilistic Performance Models of Language", Janua Linguarum, No. 150, 1973.
6. Kucera, H., "Some Quantitative Analyses of Russian, Czech, and English", in American Contributions to the 6th Int. Conf. of Slavists I, The Hague, 1968, pp. 1-44.
7. Suen, C.Y., "n-Gram Statistics for Natural Language Understanding and Text Processing", IEEE Trans. on Pattern Analysis and Machine Intelligence, PAMI-1, No. 2, 1979.
8. Herdan, G., Type-token Mathematics, The Hague, 1960.
9. Yule, G.U., The Statistical Study of Literary Vocabulary, London: Cambridge Univ. Press, 1944.
10. Kucera, H., and Francis, W.N., A Computational Analysis of Present-Day American English, Providence: Brown Univ. Press, 1967.
11. Oettinger, A., Automatic Language Translation, Cambridge, MA, 1960.
12. Gibler, C., "Linguistic and Human Performance Considerations in the Design of an Anticipatory Communication Aid", Ph.D. dissertation, Northwestern Univ., June 1981.
13. Heckathorne, C., and Childress, D., "An Integrated Computer System for Anticipatory Text Generation and Device Control by Individuals with Severe Motor Impairment", Proc. IEEE Computer Soc. Workshop on Computing to Aid the Hadicapped, Charlottesville, VA, 1982, pp. 17-23.

ADDRESS

Northwestern University
Rehabilitation Engineering Program
345 E. Superior St., Room 1441
Chicago, Illinois 60611

6.6

STENOTYPED INPUT IN REHABILITATION APPLICATIONS

Richard D. Steele

Rehabilitation Research and Development Center
Palo Alto Veterans Administration Medical Center

ABSTRACT

Currently in the U.S., the stenotype keyboard is used in one major rehabilitation application -- providing real-time captioning of television news for the hearing impaired; in Great Britain, portable systems using similar keyboards have proved helpful in individual use as well. This paper surveys such successful projects, suggests other rehabilitation applications for stenotype keyboards, and discusses select aspects of device development and operation. An explicit 'phonemic syllable' (PS) recording protocol for use in microprocessor based devices is examined, and indices of stenotype keyboard operation in PS mode are compared with indices for 'typical courtroom' (TC) recording mode.

BACKGROUND

Stenotype-like keyboards were first employed for rehabilitation purposes in January 1977, when Jack Ashley, a British Member of Parliament, began monitoring debates on a real-time speech captioner [1]. This device takes input from a palantype keyboard (which differs somewhat from the American stenotype keyboard), is operated by a professional stenographer, and displays output on a visual monitor as a sequence of phonetic syllables, abbreviations, and words; the task of deciphering the meaning of the display is placed on the deaf user.

On broadcast television, real-time captioning for the hearing impaired came three years later; the BBC introduced it in January 1980 for President Reagan's inaugural address [2]. In late 1982, the American network ABC began a similar service, using stenotyped input, for its "World News Tonight" [3]. In both countries, stations aim at providing high-quality orthographic output, with a minimum of lapses into phonetics. Although this requires look-up dictionaries of over 70,000 English words, turnaround time on the American system (InstaText) can reportedly be as low as five seconds [4].

MICROPROCESSOR BASED DEVICES

The television captioning systems of Britain and America employ expensive equipment and sizable data bases for rapid transcription of stenographic input; at current costs, these systems remain uneconomical except where large audiences are reached. In contrast, inexpensive microprocessor based devices for personal use, like Mr. Ashley's, appear both feasible and useful. Work at several centers around Palo Alto, including the VA Rehabilitation Research and Development Center, is in progress exploring three possible applications:

1) a speech captioning device for some hearing impaired persons, similar to Mr. Ashley's but with a stenotype (rather than palantype) keyboard. This device will be operated by a hearing stenotypist, producing output of phonetically spelled syllables for visual display; it could either be dedicated to a single individual, or employed at gatherings of the deaf.
2) a voice output communication aid for some speech impaired persons. This device is operated directly by the disabled person, and interfaces to a speech synthesizer for voice output; it could be used, for example, to allow profoundly deaf individuals to generate their side of a telephone conversation.
3) a speech file editor for some blind persons. This device will be operated by the blind person, permitting the creation, storage, retrieval, editing and output of 'speech files', either as synthesized voice or as hard copy.

THE STENOTYPE KEYBOARD

The stenotype keyboard permits extremely efficient machine entry of thought or spoken utterances. As Figure 1 shows, it contains four major components:

1) a numeral bar running the full width of the keyboard,
2-3) two full-width key banks, each with ten consonant/punctuation keys in a line, and
4) four vowel keys in a third bank, located furthest forward and clustered slightly to left of center.

The STENO Keyboard

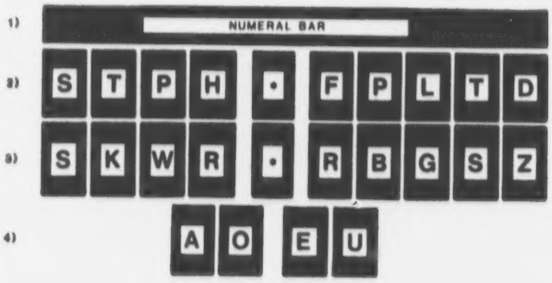

FIGURE 1

The keyboard is operated by using the fingers and thumbs of both hands to play sequences of 'chords': the thumbs operate the four vowel keys, and the remaining fingers of the hands operate the clusters of consonant/punctuation keys. The chords record phonemic syllables and abbreviations. In phonemic syllabic recording mode, the small- through index-fingers of the left hand take down the consonants beginning the syllables, the thumbs capture vocalic nuclei, and the index- through small-fingers of the right hand record syllable-final consonants. Each stenotyped chord produces a single line of stenographic transcript, with phonemic syllables obligatorily containing a vowel or diphthong, which may be preceded and/or followed by one or more consonants. In transcripts of conversations recorded stenographically, there are no indications of word boundaries per se, just strings of stenotyped lines of which some represent syllables, others -- abbreviations, and yet others -- punctuation marks.

ADAPTED RECORDING PRACTICES

Work at our Center is underway to establish workable, efficient stenographic recording practices for use in microprocessor based devices. These will be different from those used in large systems (e.g. the television captioning systems) for the obvious reasons -- constraints on processing power and memory. In attempting to produce orthographic English output, the large systems must deal with transcripts which contain myriad ambiguities and variants. As an example of the complexity of the task, the word 'duplicate' may be stenographically recorded 42 different ways [5]. In their television captioning system, the British use a longest string match technique coupled with 'two chord look ahead' [6]. Such techniques require considerable computing power and extensive data bases, surpassing the resources of microprocessor based devices.

Our smaller, less expensive devices will benefit from recording practices which are straightforward and consistent: the approach currently under investigation, called "phonemic syllabic" (PS) recording, meets these criteria. It requires that the user record each syllable in turn, capturing each phoneme explicitly and accurately; in essence, it represents the way in which stenographers operate when they encounter unfamiliar proper names (for which there are no abbreviations) in court testimony. The advantage for the system is, of course, that there are neither ambiguities nor abbreviations to look up in a dictionary. Processing focuses on mapping each syllable directly onto the output format; this is done without reference to neighbors, which eliminates the need for the computing power and data bases of the television captioning systems.

PS recording is best suited to production of voice output, since the resultant phonemic syllables, when spoken by a commercial speech synthesizer, produce quite comprehensible speech. However, visual displays -- such as the one used by Jack Ashley -- should prove helpful to many hearing-impaired people. Eventually, abbreviations will be reintroduced into the picture, yielding an 'extended phonemic syllabic' (EPS) recording mode, more efficient than straight PS recording, and specifically tailored to our chosen purposes. This lies in the future. The paragraphs below compare traditional courtroom recording practices only with straight "phonemic syllabic" recording.

The following methods were used to compare "traditional courtroom" (TC) recording practices with "phonemic syllabic" (PS) recording mode. A certified court reporter stenotyped an unfamiliar, 400+ word newspaper article, which was read to him at normal speaking rates [7]. The same article was then transcribed stenographically by the author, using PS recording protocols. To verify that the PS stenographic transcript was phonemically accurate and complete, software converted it into phoneme strings to drive a TSI PROSE 2000 speech synthesizer; the transcript was corrected and the cycle repeated until the voice output was acceptable. Then, the numbers of pressed keys, activated fingers, and transcript lines for both the TC and the PS transcripts were determined. From these, the indices of operation below were calculated for each recording mode.

RESULTS

Explicit "phonemic syllabic" (PS) recording on the stenotype keyboard for voice output was shown to be feasible technically. English speech can be produced with any desired level of phonemic accuracy, the quality of voice output depending on the speech synthesizer. However, employing PS mode requires modification of "typical courtroom" (TC) recording practices, such as:

Simplification Procedures

Work-saving practices of the following types characterize TC but not PS recording:

Apocope -- the omission of final consonants from certain post-vocalic consonant clusters (e.g. "bes'", for "best"); all clusters must be fully recorded in PS mode.

Syncope -- skipping over schwas in the middle of words, which allows entire chordstrokes to be dropped (e.g. "tel'phone", for "telephone"); such syllables must be recorded in PS mode.

Abbreviation -- for common word parts (e.g. "- G S" for "-tion"), for common words (e.g. "R O R T" for "report"), and for common word combinations (e.g. "S A" for "is a"); abbreviations are disallowed in PS recording.

Recording Protocols

Replacement of segments and consonant clusters with simpler or related ones characterizes TC but not PS recording:

Initial consonants -- missing are recording protocols for [z-], [ž-], [ð-], [θw-], [gw-], [šl-], [šr-], [šw-]; they must be added for PS recording.

Vocalic nucleii -- absent are recording protocols for [-ə-] (e.g. 'but') and 'palatalizing' [-ü-] (e.g. 'cute'); the various pronunciations of orthographic '-oo-' (e.g. 'good', 'blood', 'food') must be assigned differing recording codes.

Final consonants -- to be added are recording protocols for the following final consonants and consonant clusters; the rules below are ordered, and represent some 85 consonant clusters:

a) [-θ-], [-ð-], [-v-] and [-ž-], either alone or in clusters,
b) clusters containing [-s-] followed by [-p-], [-t-], or [-k-],
c) clusters containing [-l-] followed by a labial, affricate ([-č-] or [-j-]), [-n-], or [-k-],
d) clusters containing [-n-] followed by an affricate,
e) clusters containing [-ŋ-] followed by a velar,
f) clusters containing [-r-] followed by [-b-], [-f-], [-č-],
g) clusters containing [-m-] followed by [-p-], and
h) the cluster [-zd].

Indices of operation

The following section compares indices of operation using the stenograph keyboard in PS and in TC recording modes; it gives some quantitative indication of the workload 'cost' to the operator of using PS over TC recording techniques. Figures for TC are only typical, not exact, due to variability of practices among court stenographers.

In comparison to TC mode, PS recording incurs an incremental work cost in each of indices of operation; the increases, however, are modest. Specifically, to record a given number of words:

- a) the cumulative number of stenograph lines required in PS mode is approximately 29% greater than in TC;
- b) the cumulative number of finger motions used in PS mode is some 33% greater than in TC; and
- b) the cumulative number of keys depressed in PS mode is roughly 49% greater than in TC.

At the level of the individual stenograph line, the differences are very modest. On the average line:

- a) the average number of finger motions used in PS mode is only 3% greater than in TC;
- b) the average number of keys depressed per finger in PS mode is just 12% greater than in TC; thus
- c) the average number of keys depressed per line in PS mode is approximately 15% greater than in TC.

These latter figures are encouraging, since they indicate that most of the work increase comes in 'serial' form -- that is, in a lengthening of the overall text -- rather than in 'parallel' form -- that is, in a denser packing of material per line.

DISCUSSION

These results suggest that the main result of the adoption of PS recording practices will be somewhat slower keyboard performance. Precisely how much slower is uncertain, because the studies above establish only the slowdown attributable to increased workload (e.g. number of keys pushed, number of fingers pushing, number of lines recorded); it remains for the effect of the second component -- more explicit encoding -- to be established. This will be addressed in future studies.

Questions of encoding and decoding demands take on particular significance in rehabilitation contexts. Many questions need answering to establish how to adapt input/output to enhance access by disabled populations. For example, how should a 'real-time' visual display of speech be implemented? What material should it contain, and how should it be formatted? Will different approaches be required for the prelingually and postlingually deaf? And can other work on speech displays for the deaf (e.g. Vidvox [8]) help resolve these questions? What is the nature of language representation among deaf individuals, both pre- and postlingually, who might want to operate the stenotype keyboard for speech output, and what effect might it have on their performance? Many questions are opened for study, and answers could have beneficial effects not only for the specific disabled populations, but for general theoretical understandings and clinical work as well.

ACKNOWLEDGMENTS

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REFERENCES

[1] Downton, A., and A. Newell. 1979. An Assessment of Palantype Transcription as an Aid for the Deaf. INTERNATIONAL JOURNAL OF MAN-MACHINE STUDIES, 11:667-80.

[2] Beard, I. 1983. How British Palantype Reporters are Helping the Deaf. NATIONAL SHORTHAND REPORTER, 44,3:24-26.

[3] Associated Press. 1982. Instant TV Captions for Deaf Begin Tonight. SAN JOSE MERCURY. October 11, 1982.

[4] Matter, J. 1983. Pilot Project: Work with Hearing Impaired Students. NATIONAL SHORTHAND REPORTER, 44,3:27.

[5] Translation Systems, Inc. The Word Duplicate Written As A Three Stroke Word Stenographically. TOMCAT PROMOTIONAL FOLDER.

[6] Booth, A. and M. Barnden. 1979. Voice Input to English Text Output. INTERNATIONAL JOURNAL OF MAN-MACHINE STUDIES. 11:681-91.

[7] United Press International. 1982. Sex Suit - Employee Accuses Rights Chief. SPOKANE CHRONICLE. August 5, 1982.

[8] Russell, Y., D. Ruder. 1983. Vidvox, A Communication Aid for Deaf Persons. PROCEEDINGS OF THE SIXTEENTH ANNUAL HAWAII INTERNATIONAL CONFERENCE ON SYSTEM SCIENCES, 500-08. Honolulu: January 1983.

ADDRESS

VA RR&D Center (153)
3801 Miranda Avenue
Palo Alto, CA 94304

AN OCULO-ENCEPHALOGRAPHIC COMMUNICATION SYSTEM

Erich E. Sutter

Smith-Kettlewell Institute of Visual Sciences

ABSTRACT

A new concept in gaze-controlled communication is introduced. It employs a matrix of visual stimuli. The selected target is identified from the user's EEG.

BACKGROUND

A sizable segment of the handicapped population is nonvocal and has no adequate motor output for communication by means of hand or foot switches or head pointers. There is at the present time no adequate communication device commercially available to cover this need. Since most persons in this category have adequate vision and oculomotor control, it has been suggested (1) that eye movements might be an effective output channel. The more sophisticated designs among these systems have great potential in regards to speed and efficiency, since they permit random access to a two-dimensional array of selectable elements. This feature makes gaze-controlled communication an attractive solution even in cases where operation of a single switch is possible. A line of gaze system which operates on the basis of combined tracking of eye and head position has been studied elsewhere (2,3). The approach chosen in the present study circumvents the difficult tracking problems. It employs electrical signals from the scalp to identify the selected target.

THE GENERAL CONCEPT

The oculo-encephalographic system represents a new approach to gaze-controlled communication. In monitoring the visual evoked response on the scalp it taps into the human visual process at the latest possible stage and thus utilizes as much as possible of nature's own way of solving the visual control problem. In this way many of the problems encountered in other possible approaches are circumvented. There are no delicate and expensive optical or mechanical parts necessary to detect and track eye and head position. Instead the necessary signal is derived from a pair of simple EEG electrodes pasted to the scalp on the back of the head. No positional calibration is needed. Unlike other systems it does not determine the direction of gaze and derive from it what the target is. Instead it determines directly which one out of a number of stimuli the person is looking at. Consequently there is no positional drift involved.

Many of the problems encountered in the development of other gaze-controlled communication systems are absent in this approach. They are replaced, however, by one major difficulty which has to be overcome. It is the problem of fast and reliable extraction of tiny responses from a very complex EEG signal which, in addition, can be contaminated with muscle artifacts. This problem can be solved by means of software rather than hardware. Since software is generally much less expensive than optical and electro-mechanical hardware, a system of this type promises to be much more affordable than eye tracking systems.

The major advance toward a solution of the signal extraction problem came through a novel and highly efficient analysis technique. It forms the basis for an experimental system which has been developed and tested.

THE EXPERIMENTAL SYSTEM

The user sits comfortably in front of a CRT display which consists of a matrix of 32 flickering fields. A keyboard character is assigned to each field by means of a transparent overlay. The visual evoked potential is derived from a pair of electrodes attached to the back of the head by means of EEG paste. The signal is amplified, filtered and sampled by the A/D converter of a computer (Fig. 1).

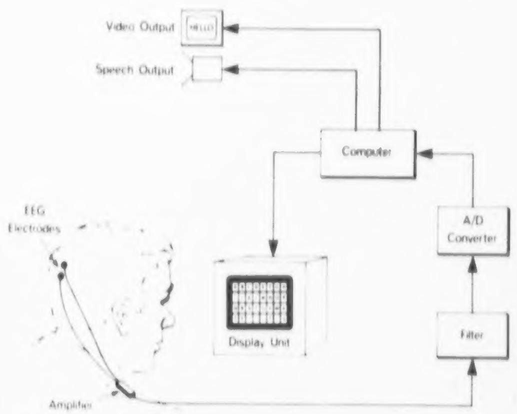

Figure 1.

The user selects a character on the display simply by looking at it. After approximately 1.5 to 2.5 seconds the system recognizes which field was selected and outputs the corresponding character to a speech synthesizer and a video terminal. Through the audio-feedback the user verifies correct recognition and proceeds with the next selection.

THE UNDERLYING PRINCIPLE

Every one of the 32 flickering fields represents a separate input to the visual system of the user. Only one output is derived from the person's scalp. The special flicker sequence used for the inputs makes it possible to derive the contribution of every input to the overall scalp response. The fovea; i.e., the central part of our visual field, has a larger representation on the visual cortex than the surrounding areas. The central stimulus thus produces much more response power per unit area than the more peripherally located stimuli. The stimulus element which is looked at can thus be identified by the size of its contribution to the overall scalp response.

IMPLEMENTATION

The task of finding the stimulus field which produces the largest response can be solved by sequential stimulation of all the fields and measuring the corresponding responses. To achieve adequate speed and efficiency a novel technique of simultaneous testing was introduced. The basic concept and its merits can best be demonstrated in comparison with the conventional approach of sequential testing.

Consider the case of 31 inputs which are sequentially tested with flashes. To prevent overlap of the major response components the flashes have to be spaced at intervals of approximately 300ms. A complete test of the entire input array will thus take 31 x 300ms or 9.3s. Unfortunately one sample of each response is not enough to provide an adequate response estimate. Assuming that 16 responses are necessary we arrive at total time of 148.8 seconds; i.e., about 2.5 minutes for an adequate test.

The same task can be accomplished in a fraction of the time if we use a technique of simultaneous rather than sequential testing. At 300ms time intervals we don't flash just one, but 16 out of the 31 inputs. Whether or not a particular input is flashed in the next time interval is determined by a special binary sequence (m-sequence). If the next element in the sequence is a 1, the input is flashed; if it is a zero, it is skipped. The sequence is the same for all inputs except for a relative delay of one step from one input to the next. M-sequences are always of length $2^n - 1$ where "n" is an integer. In our example the length is 31.

Even though 16 inputs are always tested simultaneously, the contribution from each input can be perfectly isolated. This is due to a special property of m-sequences. It can be shown that if we multiply the response with 1 in those time intervals where a particular input is stimulated, and with -1 where it is skipped, and we subsequently average this modified response sequence over all 31 time intervals, we obtain the average response contribution of this input. The responses from all the other inputs cancel out over the period of a full stimulation cycle. The response estimates obtained in this way are averages of 16 responses, just as in the sequential test considered earlier. They are, however, obtained from a single stimulus cycle of only 9.3s duration.

The efficiency of this technique can be further increased by reducing the temporal spacing between the transient stimuli. It can be shown that for linear systems the isolation of the input channels does not break down, even if the individual responses start to overlap. It is sufficient that an adequate relative delay of the m-sequence inputs from one channel to the next is maintained. To meet this requirement longer m-sequences (length 63, 127, ...) have to be used. It is desirable to increase the frame rate to the point where the visual system is maximally stimulated. Optimal efficiency is reached when the cross-power between the input sequence and the foveal response contribution is maximal. It is thus possible to "tune" the system to the human visual evoked response. (Note: When the length of the m-sequence is increased to 63 or 127 with a corresponding increase of the relative delays between inputs to 2 or 4, it becomes possible to resolve 32 instead of 31 inputs.)

The evoked response to a flash has the peculiarity that it changes polarity depending on whether the flash is presented in the upper or lower half of the visual field. For this reason every stimulus element is divided into an upper and lower half. By countermodulating the two halfs (one half is flashed whenever the other one is skipped) their contributions to the foveal response will add rather than cancel in the above averaging procedure.

Once the response contributions of the individual stimulus fields have been isolated, they have to be measured and the largest one has to be determined. A suitable measure is given by the square root of their power:

$$\int R_i^2(t)\,dt; \quad R_i(t) \text{ response of input i.}$$

It can be shown, however, that the effect of noise contamination can be reduced if, instead of squaring the responses R_i, we multiply them with an appropriate response template:

$$\int R_i(t)T_i(t)\,dt.$$

The template T_i is the foveal response for input i. Since all templates are identical up to a relative delay, only one has to be recorded. In a separate recording session the subject fixates one particular field on the display with all the other fields masked off. For good signal-to-noise ratio, 10 to 20 minutes worth of data are accumulated in small segments. Once a template has been obtained for a particular person it can be used indefinitely, as long as the electrode placement is not changed.

The use of a template brings an additional advantage. It permits us to double the number of selectable stimulus elements without resorting to a longer input cycle. We add a second set of 32 fields which is modulated with the inverted input sequences of the first set. When the response contributions are extracted as described earlier, they are also inverted with respect to the first set. Unlike the computation of the power, the multiplication with the template preserves this minus sign and thus makes the second set discriminable from the first one. This feature was implemented and successfully tested.

It is clear from the above considerations that the response to an entire stimulus cycle is required for accurate isolation of the response contributions. Such a response cycle is stored in a rotating buffer. With accumulation of every new data point, the last sample in the buffer is dropped. All the scalar products between responses and template vectors are updated and the largest one is selected. Before an output of the corresponding keyboard character isgenerated, three conditions have to be satisfied:

1. A response contribution has to be larger than all the others.
2. It also has to be larger than a given threshold value.
3. It has to be maximal for a given length of time.

The threshold criterion is designed to prevent false responses. The threshold is proportional to the square root of the total power of the EEG data coutained in the rotating buffer. It is updated with the accumulation of every new data point. When the user generates more muscle artifacts by head movements or chewing, the overall signal increases, but not the actual response power. The threshold will thus be pushed up and out of range so that no false crossings can occur. This criterion makes the system self-calibrating.

The time criterion also helps to eliminate spurious responses of the system. It acts as a low-pass filter reducing the susceptibility to fast fluctuations.

The response rate is determined largely by the length of the stimulus cycle. Whenever the user shifts his or her gaze to a new stimulus element, it takes time for the rotating buffer to be filled with the corresponding data. A response will generally occur after about 2/3 of the buffer has been updated. With a longer stimulus cycle the response of the system becomes slower but more reliable, since the estimate is based on more data. At present, the best performance is reached with a cycle length of about 2.5 seconds.

PRESENT PERFORMANCE

The present system has either 32 or 64 elements to choose from. Under favorable conditions (little muscle artifact) the time for a sequence of 10 consecutive responses is around 20 seconds. If the user generates muscle artifacts due to minor head movements, the response time becomes longer. Occasional errors may occur, depending on the setting of the criteria discussed in the previous section. If the user purposely generates strong muscle artifacts, as for instance by chewing, the system stops working. The spatial resolution of the system is about 1^{o} of visual angle in the horizontal and vertical direction. The user should thus be at a distance from the display at which the individual fields subtend at least $1^{o} \times 1^{o}$.

FUTURE CONSIDERATIONS

The performance of this oculo-encephalographic communication system depends on many variables which have not yet been investigated and optimized. As possible alternatives for the flickering hemifields, appearance or contrast reversal of gratings or checkerboard patterns will have to be tested. For each stimulus geometry the placement of the electrodes on the scalp needs to be optimized. Perhaps the largest improvement in performance can be expected from special nonlinear filtering techniques for the elimination of muscle artifacts. With such filtering the range of possible users of this communication system is greatly increased, since it would not be as susceptible to uncontrollable head movements.

It is almost certain that speed as well as reliability can still be significantly improved. There are, however, certain theoretical limits which cannot be overcome. Due to the bandwidth of the human visual evoked response, the information flow which can be reached is limited. At present we are still far from reaching these ultimate limitations.

REFERENCES

1. Rosen, M., Drinker, P., and Dalrymple, G., "A Display Board for Non-Vocal Communication Encoded as Eye Movements." Proc. of the Conf. on Systems & Devices for the Disabled, 1976, 70-71.
2. Foulds, R. and Fincke, R., "A Computerized Line of Gaze System for Rapid Nonvocal Communication." National Computer Conference, 1979.
3. Friedman, M., Kiliany, G., and Dzmura, M., "Eyetracker Communication System." Proc. 5th Annual Conf. on Rehab. Engineering, 1982, 27.

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ADDRESS

Smith-Kettlewell Institute of Visual Sciences,
2200 Webster Street, San Francisco, CA 94115.

6.8

EQUIPMENT-FREE COMMUNICATION FOR THE SEVERELY DISABLED

Christopher R. Sprague, PhD*, Cambridge Nursing Home

Linda G. Sprague, DBA**, University of New Hampshire

ABSTRACT

Two systems which allow a person without speech and with severely limited motor skills to communicate if he can spell are presented. Both systems are easy to use and can be adapted to the special needs of an individual.

INTRODUCTION

One of us (C. R. Sprague) suffered a massive pontine hemorrhage in early 1977. The stroke left him quadriplegic non-vocal; he cannot speak or write but can reason and conceptualize as before the stroke. Methods for communication have been developed to exploit whatever limited physical capability he has had at various stages of progress since the stroke.

The development of micro-computer technology is making possible increasingly effective and efficient communication for the severely disabled. While powerful and versatile, this technology has some important drawbacks: for one, the user must be "connected" to the technology in order for it to work. This implies as well that such technology must be adapted to the specific physical limitations of each user -- usually a time-consuming engineering task.

Once designed and implemented, these communication technologies share a common limitation: communication is not possible during baths and showers, during certain therapies and procedures, or while the equipment is under repair or renovation. For these reasons, two equipment-free systems for communication have been developed and are offered as supplements to the burgeoning communication armamentarium.

A BINARY CHOICE SYSTEM

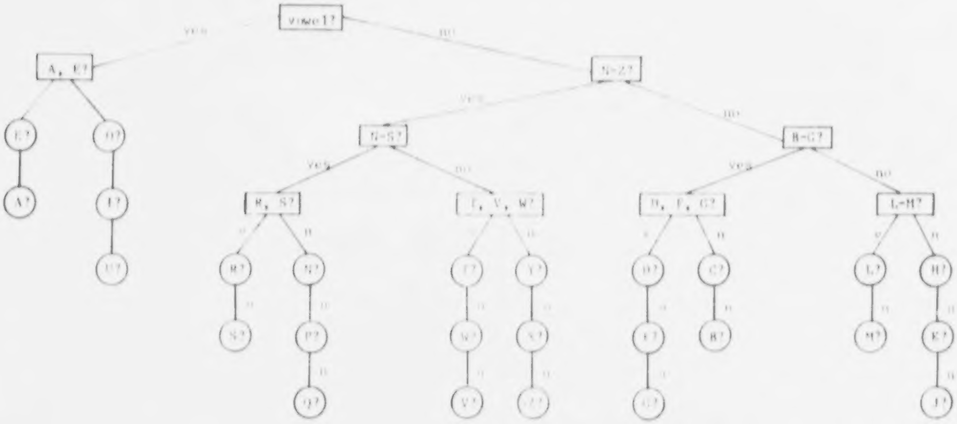
For the first several months after his stroke, C. R. Sprague was dramatically limited in his ability to communicate. It eventually became apparent that eye-blinks (1 for "yes", 2 for "no") could be used with some degree of reliability in spite of substantial third nerve damage which made controlled blinks difficult to carry out and equally difficult to understand. Since both authors are familiar with information theory, and information economics in particular, it became immediately apparent that a binary choice system which incorporated relative letter frequencies should be designed to make com munication as efficient as possible.

L. G. Sprague devised a set of questions which would lead to choice of a letter of the alphabet. C. R. Sprague used this tedious scheme to redesign the question set in order to improve the information content of each response. The result is shown in Exhibit 1: it is a spelling system based on the relative frequencies of letters of the alphabet. The user's response to each question (in a box) leads as efficiently as possible to the desired letter.

The development of this system provided C. R. Sprague with a means for initiating communication on a topic of concern to him. This ability to pose questions as well as describe specific desires was a critical factor in relieving the terror of being "locked in" -- although slow, this system did permit full communication. It also provided those caring for him with needed information without the frustration of trying to guess what he wanted.

Exhibit 1

Spelling System based on Relative Letter Frequency with Binary Choice



An Example of the Use of the Binary Choice System

For this interaction it is assumed that the transmitter knows the alphabet and can spell. The receiver uses a copy of Exhibit 1 to ask questions in the proper sequence, letting the answer to one question determine the next correct question. The receiver usually finds it convenient to have pencil and paper on hand to take down messages.

example

Receiver: "Do you want to spell something?"
Transmitter: "Yes" (1 eye blink)
Receiver: "Is the first letter a vowel?"
Transmitter: "No" (2 eye blinks)
Receiver: "Is it N through Z?"
Transmitter: "Yes" (1 eye blink)
Receiver: "Is it N through S?"
Transmitter: "No" (2 eye blinks)
Receiver: "Is it T, V or W?"
Transmitter: "Yes" (1 eye blink)
Receiver: "Is it T?"
Transmitter: "Yes" (1 blink)

It takes a minimum of three responses to get to a specific letter; in the example above, it took 5 responses to get to the letter T. In the worst case (Q, V, Z, G or J) it takes 6 responses to identify a specific letter. This is not proposed as a speedy system but as an expedient system to permit someone with full mental capabilities to respond as best he can given virtually no physical capabilities and no equipment available to permit communication.

The speed of response of this system improved over time as C. R. Sprague's physical capabilities improved. When it became apparent that he would be able to shake and nod his head with some degree of reliability, agressive physical therapy was directed to that end in order to improve receivers' ability to understand this limited mode of communication. Time to transmit and receive a sentence of approximately 5 words went from days (for the first attempts) to minutes when the effects of the physical therapy and time had improved C. R. Sprague's ability to reliably shake and nod his head.

This binary choice system, as shown in its entirety in Exhibit 1, can be used as is with any person who knows the alphabet, can spell, and can reliably indicate "yes" or "no" somehow. It is our experience that head shakes and nods are far better received and properly interpreted than other modes, but people working with a disabled person can of course be trained to interpret other signs.

A FIVE-FINGER SPELLING SYSTEM

About a year after his stroke, C. R. Sprague was able to indicate the numbers one through five reliably with his left hand. He was not able to indicate arbitrary fingers as is required for sign language, but was able to indicate quantity. At the suggestion of Nancy Lefkowitz, a speech pathologist at the Massachusetts Rehabilitation Hospital in Boston, the authors devised a system to take advantage of this improved physical capability to speed his communication.

Exhibit 2 shows the system developed for C. R. Sprague. As with the earlier system, this is based on relative letter frequency. The letters have been arranged in a 5 by 5 matrix of letters to accommodate C. R. Sprague's "sequence of ease" -- in other words, C. R. Sprague finds it easiest to indicate a 5, then a 4, then 1, 2, and finally 3. In our experience, this sequence of ease (5-4-1-2-3) is the sequence of ease for most people, disabled or not.

To use the system, the transmitter indicates with one hand two consecutive numbers for each letter. The first number is interpreted as the "row" index; the second number calls out the "column". Thus, the word "row" is 1-5, 5-1, 3-4. A special symbol -- a fist or a zero, for example -- can be used to indicate end-of-word; another can indicate end-of-message.

Exhibit 2

Spelling System based on Relative Letter

Frequency with Sequence of Ease 5-4-1-2-3

columns

	1	2	3	4	5
1	C	Y	B	H	R
2	P	V	J	F	D
3	K	X	Z	W	L
4	S	M	G	N	T
5	O	I	U	A	E

row, then column

("Q" missing: for QU use KW)

System Development

Development of this system required three sets of decisions:

1. Decide which letter to omit: we chose "Q" because "KW" adequately simulates "QU" and "Q" alone is rare.

2. Determine the sequence of ease: C. R. Sprague finds it easiest to indicate a 5, most difficult to indicate a 3. His full "sequence of ease" is 5-4-1-2-3. The assumption is additive linearity; thus, 4-2 is exactly as difficult (or easy) to indicate as is 3-5.

3. Decide the order of letters: our son had a cryptography book which lists the letters of the English alphabet in order of their frequency of appearance which had been used for the development of the previous system. This was sufficient information to develop the new system (See Exhibit 3 for English relative letter frequencies.) It was necessary only to fill in the 25 spaces in the letter matrix in order from the easiest (5-5 or "E") to the most difficult (3-3 or "Z"). Note that while there is but one of each, five positions are tied for middle difficulty: 5-3, 4-2, 1-1, 2-4, and 3-5 are all equally difficult (or easy). The order was changed slightly to keep all the vowels together for ease in memorization.

An Example of the Use of the Five-Finger Spelling System

For this interaction it is assumed that the transmitter has memorized the matrix although that is not necessary as long as the transmitter can see the same matrix seen by the receiver. The receiver usually finds it convenient to have pencil and paper on hand to take down messages:

example

Transmitter shows 1.
Receiver says, "one".
Transmitter shows 4.
Reciever says, "four, H" (1-4 = H).
Transmitter shows 5.
Receiver says, "five".
Transmitter shows 4.
Receiver says, "four, A" (5-4 = A), and
so on through P (1-2) and another P (1-2).
At this point the receiver guesses, "HAPPY"?
Transmitter shakes his head, "no".
Receiver guesses, "HAPPEN".
Transmitter nods his head, "yes".

Rebecca Knox, the Occupational Therapy Consultant to the Cambridge Nursing Home, has timed the use of this system. Assuming that the receiver calls each row and index and each letter as received from the transmitter, communication can proceed at the rate of two words per minute. Guessing the letters needed to finish the current word, or words needed to finish the current sentence, lowers the transmission time at the cost of sometimes guessing wrong.

This system makes limited intellectual demand on the receiver. The major problem with the system is the tendency of some people to take the first number as the column (as opposed to the row) index. This is easily remedied once recognized by spelling out the word "backwards" backwards. Nurses, therapists, aides, colleagues and friends have been taught to use the system. Training takes only a few minutes; experience with the system by a receiver improves the speed. If the transmitter is capable of using both hands, the row (right hand) and column (left hand) can be indicated simultaneously, doubling transmission speed.

SUMMARY

These systems can be used by victims of trauma, people suffering from one of several degenerative diseases or even prisoners (by tapping with the "sequence of ease" set to 1-2-3-4-5). In short, these systems can be used anywhere the power of speech is lacking but the power of ratiocination is not.

The Binary Choice System should be used exactly as shown in Exhibit 1. The Five-Finger Spelling System can readily be adapted to any sequence of ease using the relative letter frequencies shown in Exhibit 3. If physical capabilities improve, the user can progress from the slower (Binary Choice) to the speedier (Five-Finger). These systems cannot compete with computer-based systems for communication; they are intended [illegible] supplements for situations when the technology [illegible] not available.

This paper was prepared with the aid of the MIT UNICOM.

Exhibit 3

Table of English Letter Frequencies

"Approximate number of times this letter occurs in 100 letters. Since no fractions are used, several groups of frequency numbers appear to be identical. They are not. Each letter occurs less often than the letter above it."

letter	frequency per 100 letters
E	13
T	10
A	8
O	8
N	7
R	7
I	6
S	6
H	5
D	4
L	3
F	3
C	3
M	3
U	2
G	2
Y	2
P	2

All others less than 2, in this order:
W,B,V,K,X,J,Q,Z

From: Secret Codes and Ciphers by Bernice Kohn, Prentice-Hall, Englewood Cliffs, New Jersey, 1970, pages 55 and 56.

Address: Professor Linda G. Sprague
Whittemore School
University of N.H.
Durham NH 03825

Matching Non-oral Subjects Needs and Skills to Augmentative Communication Systems: Results of a Three Year Study

A. M. Cook, C. L. Coleman, A. M. Preszler,
D. L. Dahlquist and L. S. Meyers
Assistive Device Center

ABSTRACT

Nineteen non-oral subjects who received augmentative communication systems and follow-up procedures were examined in terms of the goodness (quality) of fit between subject capabilities and needs and system characteristics. A hierarchy of seven features was used to evaluate the fit.

INTRODUCTION

The results reported here are based on a three year project. The goal of this project was to identify communication characteristics pertinent to matching communication device capabilities to the needs and abilities of potential users with communication disabilities. At the outset of this project the field of non-oral communication was rapidly, if not systematically, developing. Many new augmentative communication systems (ACSs) were being introduced into the commercial marketplace. Operator requirements and system features were, however, not sufficiently specified to provide a good basis on which to match the hardware to user needs and abilities. At the same time, we proposed that systematic and exportable procedures to assess such needs and abilities were not readily available. Further, these two information domains, even if existent, are by themselves inadequate. What was required was a model or set of procedures by which these domains could be related to each other in such a way that an appropriate ACS could be matched to candidate users. The thrust of our project was thus directed at evaluating ACSs and developing assessment tools and approaches for non-oral children in an effort to approach the problem of creating a match between the non-oral children's goals and needs and augmentative communication system characteristics.

BACKGROUND

The objectives originally proposed included identification of the following: critical features of devices, critical features of human performance and a process for selecting and tailoring systems to meet educational needs. Subobjectives included the following: specifications of procedures to characterize devices in terms of required user skills, development of screening and assessment procedures of the children and development of follow-up procedures once the recommended system(s) was acquired. These are discussed in detail in reference (1). The various objectives and subobjectives were met with varying degrees of success. The features of devices and human performance have been identified. Methods have been developed for determining if the system will meet educational needs, and since educational environments usually involve communication skills common to other communication systems, we have found this to be applicable for clients in other settings. The procedures for characterization of devices and screening and assessment proecdures have been described in detail (2, 3, 4, 5). A more systematic approach to follow up procedures is still needed. There is interesting work being done in this area by Bolton and Dashiell (6) which involves structured observations of systems in use.

METHODS

Subjects

The subjects consisted of 42 students in the San Juan and Sacramento City Unitied school districts, Sacramento County, CA. Referrals were made by teachers, therapists and principals. We initiated a screening with all children whose parents or guardians returned the letters. The subjects (30 males and 12 females) ranged between the ages of 5 and 21 years at the beginning of the project. The types of disabilities included 32 cerebral palsied, 4 trauma, 2 developmentally delayed and 4 others.

Materials

The materials described here are those required for assessment procedures. The materials needed for device characterization vary from device to device, and one generally regarded as needed in good engineering practice.

Coleman et al. (1) contains the assessment forms. These were developed over a two and a half year period. The forms and procedures were developed through several iterations of field testing and critique. Lists of materials needed to conduct the assessments and the cognitive/language assessment are available (1). Devices, systems and other hardware as well as computer software used for assessment and implementation are documented (1, 2).

All subjects received an initial interview (5). A decision was then made to go on to the communication interview, go to the prelanguage interview or to stop because the referral was inappropriate. A prelanguage assessment was developed to meet the needs of children who had not yet acquired the language skills necessary for use of ACSs.

Following the assessment, a report describing the assessment, an ideal solution and the commercial device (with or without modifications) which would most closely match this solution was prepared. In some cases two or more devices or systems were needed to meet all the goals and needs of the subject.

A meeting was usually held following the receipt of the recommendation by involved parties. Here the practicality of the recommendation was discussed, questions answered and implementation planned. If the system was funded, we coordinated the acquisition and fitting of the system through third party payers, including involved school districts, Regional Centers, State Department of Rehabilitation, California Children's Services, private insurance companies and some service clubs and parents.

Once the system was acquired, follow up procedures began. The first portion of this was a communication performance analysis in which speed and accuracy were measured. Finally a questionnaire was sent to the significant others working with those subjects who received a system and had an opportunity to use it before the end of the project. This included about half of the subjects.

RESULTS

Nineteen subjects received augmentative communication systems and follow up procedures. Four children were either ill or moved during the project and four were diagnosed as prelanguage and recommendations were made regarding development of cognitive and physical skills. Three children had no reliable physical response, and training procedures to develop a response were recommended. One child was diagnosed as autistic and no recommendations were made. One child was an inappropriate referral since the family wanted aids to daily living rather than communication. Two children's recommendations were not implemented. The first of these two recommendations was for a subject who did not want to wear anything on his head and the recomendation was for a light beam indicator. The other recommendation was for a microcomputer and the funding agency felt that the gain in communication ability would not be worth the cost. A second less desirable system was implemented in this case.

Match of Device Characteristics to User Skills and Goals

Each of the subjects who received a system and follow up procedures was analyzed as to the appropriateness of device characteristics in meeting their needs and skills. This analysis was based on a hierarchy of device characteristics (3). These data are summarized in Table 1. Each of the categories in the first column of this table represents a device characteristic. The additional columns show how these characteristics met the needs of the subjects.

At the most basic level the systems must have characteristics that the subject can use. Since all of these systems are presently in use, this basic level of matching the device to the subject needs has obviously been met. This level is not addressed in the table. The more pertinent question is: Does the system allow maximum use of the subjects' abilities?

There is an appropriate match on all of the subject's symbol systems. All are using the highest level symbol system they are capable of using. In addition, 15 of the systems indicate room for growth on the part of the client. This is highly desirable for school age children.

The physical selection methods show a match for 16 subjects. Physical selection ability in three cases was above that which was actually used. One of these subjects is physically capable of using a larger array but cannot cognitively utilize it. This is reported as an appropriate match. Two subjects are also physically capable of using larger arrays than what they are presently using, but they lack communication skills. These subjects, who have not had a communication system, find it difficult to initiate communication, and we have started with a small number of what we hope are pertinent, useful items to encourage initiation. More items will be added as the subjects begin to initiate conversation. Thus, 17 of these are perfect matches, and the other two also are based on the communication initiation strategy adopted. Four devices have capabilities above the present use level which allows for development.

The cognitive selection methods shows a perfect match for 11 of the 19 subjects. Eight show subjects ability above present use. Although scanning and encoding are cognitively more complex than direct selection, they are not necessarily more desirable. Direct selection is frequently the most rapid system and would be the selection method of choice. Only in cases where the persons cannot use direct selection or direct selection is slower than scanning or encoding or when the directly selectable vocabulary is to small will the more cognitively complex methods of scanning or encoding be used. In all eight cases that can use higher methods but did not, speed was the deciding factor. Two of these use computer keyboards and the others all use communication boards from which they make direct selections. The systems of 16 subjects do offer the capabilities above that being used by the subject. Thus, these are all appropriate matches. In some cases teachers and therapists indicated dissatisfaction concerning the speed and/or accuracy of some of the subjects' systems. In these cases alternative physical sites and/or selection methods are presently being tried. In at least two cases further training in the use of a switch may lead to a scanning method which is faster and more accurate than the present direct selection method. This illustrates the need for in use follow up. A system may be usable, as in these cases, but still not meet subject and receiver goals. Training and reevaluation is an important step to determine if improvement is possible. These systems provided a match based on the subject's level of performance at the time of evaluation, but recommendations for specific training may lead to better systems.

Receiver and user output format showed only one case where the device, receiver and user all agreed. In two cases the device ability exceeds use. In 7 cases the receiver goals were above use and in 10 cases the subject ability was above use. In both cases of the receiver and user mismatches, the cause was a desire to use speech. All these users and receivers can understand speech and many felt it was the most desirable mode. The only presently existing speech output devices require a combination of physical and cognitive skills which are possessed by few subjects. The subjects must have good fine motor skills or understand encoding. Many of our subjects lack both of these skills. To make full use of a speech system, reading and spelling skills are also needed and most of our subjects lacked these skills. This indicates as good a match as can be achieved with present technology but also indicates a real need for speech output devices which can be accessed more readily by nonreaders and are smaller and more portable for ambulatory individuals.

Vocabulary size shows a match for 5 subjects with 14 which have subject ability above use and 15 in which the device is capable of going above present use. This would indicate that 14 are mismatches since the subjects full capability is not being used. Five subjects have large picture vocabularies but are learning Bliss or reading skills. Their systems contain the material they are learning and are used as teaching tools as much as communication systems. A picture conversation back-up system is advisable in these cases. Four of the subjects have large vocabularies but are not motivated to initiate conversation. Small arrays for specific situations are being used to try to encourage some initiation. Two subjects know more items than can be included in a small array, due to cognitive/perceptual problems, and subjects are limited to small arrays by their physical capabilities. We are presently trying to find ways to overcome these limitations. One subject is ambulatory but must use a picture system. He can only carry a few items with him at a time. This limits his vocabulary.

A summary of the vocabulary mainpulation information indicates that eleven subjects have complete agreement between subject ability and device use. In eight instances the subject ability is above what is being used. All of these were with subjects who were using communication boards. They can all use page selection but were not doing so. This is probably an artifact due to the way the communication systems are being used. The majority of our observations are in the classroom where the receiver (the teacher or therapist) chooses the subject to be studied or discussed and thus makes the board selection rather than a conversational mode in which the subject makes the selection. The use of page selection is an important feature which should be added to these in order to give the user more independence and encourage communication initiation. Sixteen of the systems had device abilities above those being used, indicating that there is room for development of additional vocabulary manipulation methods.

A summary of the device size information indicates that 14 systems show agreement for device size and subject ability. In nine cases the device can be used at a level above that of the subject, meaning that the device is more "mobile" in terms of size than the subject presently needs. This usually means that the system could be used with an ambulatory subject but the user is not ambulatory. In five cases the subjects' abilities are above that of the device. Two of these are computers which are fixed and the subject can move around in a wheelchair. The versatility of the computer was seen as being important enough to warrant its use. In addition the subjects both have communication boards which they use in other situations. One subject is ambulatory and uses a HandiVoice HC-110. She cannot use it as she walks around but its classroom and social group use outweigh this disadvantage. She uses manual signs and speech in other situations. Since neither are intelligible to strangers this presents a problem. The HandiVoice is being used to help her learn to read and spell. It is hoped that this may lead to the use of an alphabet or communication board in other situations. Two subjects use large communication boards with light beam indicators. Because the boards are so large, they are not wheelchair mountable.

SUMMARY AND CONCLUSIONS

A major restraint to more approproiate matches is the lack of technology and ingenuity to provide speech output for ambulatory subject, picture users and so on. Mismatches in vocabulary size are due to two factors. One is the lack of use of multiple boards when the subject is capable of using them. The other is a lack of a large portable picture vocabulary. In terms of size, three of the five mismatches are due to the present level of technology. Portable computers with the complex capabilities required by some subjects are not yet available and a light weight portable speech synthesizer is not yet commercially available.

The project demonstrated that it is possible to assess non-oral clients' abilities, needs and goals. We found that multiple systems are the rule rather than the exception and that systems of school age children must be flexible and/or exchangeable. An additional need which we identified was for a system that prints pictures, line drawings, Rebus symbols or some similar symbols.

ACKNOWLEDGEMENT

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REFERENCES

1. Coleman, C. L., A. M. Cook and L. S. Meyers (1982). Enhancing the educational potential of non-oral children through augmentative communication system use. Final Report of Project. U. S. Department of Education Grant #G007902261
2. Barker, M. R. and A. M. Cook (1981). A systematic approach to evaluating physical ability for control of assistive devices. Proc. 4th Ann. Conf. Rehab. Engr., 287-289.
3. Cook, A. M., C. L. Coleman, A. M. Preszler and D. L. Dahlquist (1983). A hierarchy of augmentative communication characteristics useful for matching devices to client's needs and skills, Proc. 6th Ann. Conf. Rehab. Engr.
4. Meyers, L. S. and C. L. Coleman (1982). Testing non-oral individuals for augmentative communication systems: a symbol system assessment model. Assistive Device Center Preprint. Submitted for Publication.
5. Coleman, C. L. and A. M. Preszler (1982). Philosophy and procedures involved in initial assessment of non-oral individuals. Assistive Device Center Preprint. Submitted for Publication.
6. Bolton, S. O. and S. E. Dashiell (1982). Developing social skills using augmentative communication systems. Paper presented at the California Speech-Language-Hearing Association Convention, Monterey, CA.

TABLE 1: DEVICE CAPABILITY COMPARED TO SUBJECT ABILITY

Char.	Allows max.	< theor. max.	< actual	>use
Symbol	19	0	0	15
Phys Sel	16	3	0	4
Cog Sel	11	8	0	16
Output	1	18	18	2
Vocab Size	5	14	6	15
Vocb Manip	11	8	8	16
Phys Size	14	5	5	9

Assistive Device Center, School of Engineering
California State University, Sacramento
6000 J. Street, Bldg. TOO
Sacramento, CA 95819

PLEASURES AND PITFALLS OF COMMUNICATION DEVICES

Mario P. Capozzi, M.A., C.C.C.
Pioneer Education Center
Pittsburgh Public Schools

In the area of communication devices rehabilitation engineers must come to terms with whether these devices can be modularly designed or whether they must be customized. The intent of this presentation is to familiarize this audience with the practical applications of existing communication technology in the hope that resolution of the issue may be closer at hand. The following details the attempts to augment one student's communication and emphasizes the resultant "pleasures and pitfalls."

Jennifer Lowe is fourteen years old. She has cerebral palsy, is unable to speak, and is totally dependent for basic living needs. Jenny is beautifully alert, has a winning smile, is extremely motivated, and independently "explores" strategies for using communication and environmental devices. Jenny is seated in a wheelchair insert, harnessed and supported at the trunk and legs. Her right arm is tightly secured at the wrist to her wheelchair tray and she is stabilized to prevent atonic neck reflex patterns. Thus, she moves her left arm and hand to operate her power wheelchair, or uses headsticks or headlights for direct access to language boards and keyboards. Neither operation can be completed simultaneously, Jenny either uses her left hand to move herself in her power chair or she uses her head apparatus for communication. Ongoing physical assessment continues to reveal the absence of any natural voluntary hand or foot movement for executing purposeful control.

Jenny's communication skills began at an early age, indicating affirmation and negation by two years through the questioning techniques of "Do you want this...", or "Is this...", and others. At five years Jenny used a Bliss symbol board accessed by left hand and arm movements. Her left arm was stabilized with a kydex-formed splint while a protruding pointer extended laterally from the left index finger. Although this supporting system did not provide Jenny with the desired precision for indicating keys or cells on her communication boards, she gained independence in using the language board displays.

While using the Bliss boards, Jenny developed a sight reading vocabulary, and an understanding of phonics. The generalized Bliss boards gave way to a variety of setting-specific (school and home) boards, but Jenny was frequently frustrated because the desired words for a particular occasion or thought were not always represented on the display. Spelling each word was extremely slow as a result of her poor motoric control. It was not uncommon for her receivers to become impatient and complete or "second guess" her messages.

Jenny's first experience with electronic, portable keyboards occurred at age eight. The Micon MCM was a pleasure. It was battery-powered and fit on her wheelchair tray. It displayed at least twenty-five letters across the LED screen and did not require the receiver of her message to be physically present while the message was being composed. It could be used in a variety of settings, such as home, shopping malls, hallways, and cafeterias. Jenny learned to edit her own written errors, combine words into sentences and apply such grammatical rules of plurality, non-verb agreement, and possession. To bypass the hitting of two keys simultaneously for clearing or erasing the screen, Jenny discovered the backspacing key which removed the unwanted or incorrect letter from the right side of the display. She found her "independent" communication extremely rewarding, and at the same time extremely frustrating. Her poor motor control required the sacrifice of speed for accuracy. It was not unusual to consume a half hour writing four or five word simple sentences.

In addition to the alphanumeric line that was displayed beneath the plexiglass on her wodden tray and the Micon, Jenny also began exploring the Phonic Mirror "HandiVoice" models 110 and 120. The span of arm movement required to operate the model 110 precluded success with this device. The numberical (0-9) keyboard arrangement on the 120 model was within her arm movement space and success could be attained. Although she strongly objected to the "voice" as a representation of her personality, Jenny learned to operate the system. Again wanting to control her communication, Jenny elected the direct access mode to the three number codes of the HandiVoice 120, rather than using the scanning option which would have been less fatiguing. Jenny also refused to use this device in the classroom with her classmates, not only because she disliked the voice, but also she feared her classmates' reactions to the artificiality of the vocal productions. A strategy was developed to bridge this psychological impasse. As an exercise in device training, Jenny was required to program her classmates' names. Their name codes were then written on three by five index cards. After several months Jenny agreed to demonstrate the system to her classmates. Each class member was given their coded names and a short message to enter into the model 120. The experience was successful. Jenny and her friends gained and shared an appreciation for using an augmentative device and the time involved encoding vocabulary. The acceptance by her peers helped Jenny to become more comfortable with the voice output system. All the students became sophisticated in "code" communication. It was not unusual for a student to raise their hand for attention and say "4 2 1" ("please leave me alone") or "3 0 0" ("bathroom").

Use of a coding device requires the user to become familiar with a number of codes. Given Jenny's personality, quick access to the preprogrammed vocabulary was essential. To locate desired codes a variety of telephone indexes was tried. One battery-powered index was so noisy as the plastic cards flipped to the correct letter group that Jenny could not prevent her body from flying into extension. She then had to exert overt control to get her body realigned for continued access to the system. Several other systems were tried -- all required compromises. Her concentration on the tasks had to be so intense that much of her energy was consumed searching and entering codes rather than in the message content to be sent. The pleasure of having a vocal output system did not balance with the pitfalls of excessive fatigue resulting from the demands for speed and accuracy.

The body tension required to operate these devices was directly contributing to the development of back problems. As academic demands increased and as the desire to communicate continued, Jenny was becoming more physically disabled. It became imperative to find another interface mode. At this time Jenny was using the MCM, an alphanumeric display, the HandiVoice 120, an electric typewriter, and the Canon Communicator. All these systems had component parts of a desired total system, but none met her needs. The search for the best system and improved means of interface continued.

As with electronic scanning devices, Jenny, who preferred to have her head and eyes free to explore her world, refused to use obtrusive head or chin pointers. However, her mounting frustration and fatigue motivated her to try the optical headlight pointer. Her positive experiences with this small headlight pointer changed her attitudes.

While using the headlight, it became evident that Jenny had to learn the pragmatics of language, the rules of discourse. She became quickly aware that some of her receivers could not spell or visualize letters into words as quickly as she could transmit the letters. She learned that pauses were a necessary component of interactions and that eye-contact was essential for effective communication. In addition to eye direction, pausing, turn-taking, she began to understand and effectively use other conversational strategies, such as initiation, questioning, commenting and topic-change rules. Jenny incorporated intonation and inflection into messages. She circled "O" on her language board several times accompanied by appropriate facial expressions to indicate "OOOOOOOHHHHHH!!!!" Her messages contained typical teenage slang expressions. She became a "TALKER".

A friendly engineer neighbor was impressed with Jenny's ability to use the headlight and the Handivoice 120, and convinced Jenny's mother to purchase a personal computer, promising to construct an interface responsive to her headlight and connected to her microcomputer. However, there were several disadvantages to this "homebrew" system. The first was that the signal from the headlight had to be centered on the "sweetspot" of the desired phototransistor cell. This problem was not insurmountable because Jenny was developing increased neck strength, speed and accuracy with the light indicator. The second pitfall was the slowness of the response time from the phototransistor cell to the computer. Single letters were accepted at a rate of one every three seconds or four seconds. Unfortunately, the system was not refined when the neighbor engineer was transferred to another location, and Jenny sits with an inadequate and unrepairable interface.

Recently, Jenny began experimenting with a voice entry system, The "ShadowVet". Her vocal productions were extremely limited. Initially she produced two sounds consistently, but has increased that number to five. These sounds were programmed and then recognized by the computer as system commands. Because of her limited sound repertoire this entry system may only be used in conjunction with another input system.

As a willing experimentor and an advocate of technology, Jenny watched a demonstration of a robot arm. The "Tommy Armatron" toy reacting to the manipulation of the controls by the therapist lifted a cookie from Jenny's tray and placed it in her mouth. Jenny, of course, wants one, but the existing controls are not responsive to her method of selection. Needless to say, a user-friendly type would enable Jenny to interact more independently with her environment.

The lessons to be learned from Jenny's experience are many. Obviously, communication devices have had a tremendous impact on the quality of her life. Each device contributed something toward Jenny's effective communication, but no single device met all of her communicative needs although they offered hope for something better. This presentation has not answered the question regarding modularity vs. customization, yet it does detail some vital aspects to be considered when addressing this dilemma.

NOTES

Capozzi, Marie and Mineo, Beth "Nonspeech Language and Communication Systems - Children" in A. Holland (Ed.), Recent Advances: Language Disorder, College Hill Press (in press).

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Marie P. Capozzi, M.A. C.C.C.
Pioneer Education Center
Pittsburgh Public Schools
6108 Kentucky Avenue
Pittsburgh, Pennsylvania 15206

PRESPEEC: USE OF A SOUND-COMBINATION SYSTEM BY NONVOCAL CHILDREN

Cheryl Goodenough-Trepagnier, Melanie Fried-Oken, and Beth Galdieri

Tufts-New England Medical Center

ABSTRACT

A communication aid has been designed and built which has a 300-item syllable and phoneme menu, represented by means of phonetic spelling, abstract symbols and colored backgrounds. The device has digitized speech output and operates by direct selection. Two six-year old, nonvocal boys with cerebral palsy, who do not yet read, are receiving training in the use of the device. Analyses of substitution and simplification errors and self-corrections in the course of learning are consistent with a strategy of matching the sounds produced to mental acoustic images. Preliminary results support the hypothesis that children need not have acquired reading skills in order to learn and use spontaneously a language representation system based on selection and combination of abstract sound units to form words.

INTRODUCTION

There is no medical basis for inferring a general central language processing deficit in non-speaking children with cerebral palsy, since the cerebral areas considered to play a major role in language processing are not necessarily affected by the lesions underlying the motor impairments of this condition (1). Clinical observation (2, 3) and the writings of nonvocal people themselves (4) support the contention that most children with severe CP probably have the capacity for normal language development. However until they are able to master standard spelling, they have at best severely limited means of expressing the full range and complexity of language they already comprehend. Nonvocal children typically pass through the period of their lives considered critical for successful language acquisition (5, 6), using only limited vocabulary systems.

While there is evidence that comprehension and the ability to produce fully elaborated language can develop in the absence of speech (7, 8), it is incontestable that the child with severe expressive limitations is at a considerable disadvantage in linguistic development. The grammatical hypothesis testing necessary to language development becomes difficult if the child's only option is to wait for critical sentences to be produced by others, instead of being able to produce utterances and evaluate the responses of others to them.

In view of the effects on language development and communicative function, it is generally recognized as desirable to expand the nonvocal child's language representation system as rapidly as the child is cognitively equipped to handle it, and in particular to move to an orthographic system as soon as possible. The purpose of the PreSPEEC system whose design and preliminary test results are reported here is to lower the age (that is to lower the cognitive and prior learning requirements) at which the nonvocal child can begin to use an orthographic system to communicate.

If instead of waiting until adolescence, the nonvocal child can begin as young as 6 or even younger to gain experience in producing words and sentences without vocabulary restriction, the potential for enhancement and acceleration of language development is considerable.

Current clinical practice with nonvocal children usually favors reliance on non-orthographic communication aids until the child is an accomplished reader and speller. The (standard) alphabet may be included on the language board, but pictures and symbols are taught and their use is encouraged. This is done because standard spelling by selecting letters from an alphabet has proven to be a difficult way for beginning readers to communicate. Tests of segmenting and blending, success at which usually accompanies reading success, have been used as an indicator of the child's readiness to use an alphabet for communication. Leaving aside the chicken-and-egg question of the relationship between segmenting and blending skills and reading and spelling skills, the question is raised here as to the necessity of reaching high levels in any of those skills for productive selection and combination of sounds when standard letter-by-letter spelling is not involved. More particularly, it is hypothesized that sound selection and combination can be rendered much less abstract than the tasks involved in many tests of segmenting and blending, and less abstract than letter-by-letter spelling. The means adopted to facilitate sound selection and combination and to take this activity out of the metalinguistic realm constitute a description of the PreSPEEC system.

MATERIALS

The PreSPEEC System

The PreSPEECer is a large touch-sensitive panel divided into over 300 boxes (1" by 1" for the two subjects reported on here). The device is battery-powered and includes a SPEECH-1000 board from Telesensory Systems, Inc., which provides digitized human speech output of stored words, syllables and phonemes. The PreSPEEC menu includes among its units the complete set of phonemes. The rest of the units are all syllables or multi-syllable units, chosen by means of the SPEEC/WRITE algorithm (9), with the additional restriction that only units containing an integer number of syllables were permitted (in other words, there are no isolated consonant clusters).

The features of PreSPEEC which were chosen with the aim of supporting sound selection and combination are the following:

1. Menu: a large proportion of language, 73% of all words, can be produced using syllable (or multi-syllable) units exclusively (10). Others

require some syllable plus consonant combination. There is evidence for greater 'psychological reality' of syllables than consonants (11). Syllables exist in isolation while consonants do not. Syllable representations have been shown to be more easily learnable than a 'phoneme-mapping' alphabet (12). Clearly the mental load, in terms of memory and planning requirement is less for fewer large chunks (syllables) versus many short chunks (phonemes or letters).

2. Training progression. Subjects begin with a subset of syllable-units, with no others visible on the board, until successful learning is demonstrated, and a new set of units added. Training proceeds by the following stages: immediate imitation, delayed imitation, dictation, and finally, to structured question as stimulus, with no model of the desired response, as each new set of units is added.

3. Visual Redundancy. The sound units on the menu are of necessity 'phonetically' spelled, using an orthography developed for SPEEC (13). This orthography is consistent and for the most part one-to-one (sound to spelling). Two other features are available to facilitate identification and location of the units: all syllables beginning with the same phoneme are grouped together on a colored background which distinguishes those syllables from adjacent ones; and each syllable has a shape drawn around it, corresponding to the vocalic nucleus of that syllable. In other words, the initial consonant and the vowel of each syllable are identifiable without any reference to the spelling. It should not be overlooked of course that consistent location (that is, a given syllable is always in the same place) is a very useful cue and may be the most important one for some users.

4. Immediate Feedback. Selection of a sound on the board results in spoken production of that sound, under the child's immediate control. This is probably the single most important contributor to making this system useable by pre-readers. The alphabet user must make selections which are rather abstractly related to sound. Furthermore, it is usually necessary to wait until the whole word is spelled before feedback is obtained. Even if this alphabet is part of a device which includes a text-to-speech system, the user whose language is still developing is at a disadvantage compared to the PreSPEEC user. The alphabet user with a speech output device can only get letter-name feedback until the whole word is entered. Until that point there is no way to obtain confirmation of his or her sound-symbol hypotheses. The PreSPEEC user can get immediate sound feedback from each selection -- sound feedback which remains constant when that selection is combined with others to form words and sentences. The PreSPEEC user thus has a chance to get an immediate test of his/her notion of the relationship of that target to the sound s/he has in mind, an ideal situation for learning.

5. Functionality. The availability of speech output and a repeat key which allows replay of item sequences' and the communication rate resulting from use of a system with low C (that is, a minimal number of selections per word) (9) are expected to facilitate verbal interaction with others and by doing so enhance motivation to learn and use the device. It should be noted that the receiver need not attend to the spelling, symbols or colors, but only to the spoken output, with expected positive effects on receivers' motivation to communicate with the PreSPEEC user.

Subject Selection

Five young nonvocal boys with severe cerebral palsy were assessed for their potential as PreSPEEC candidates. The basic criterion for inclusion in the study was that the child not yet be reading, but that the prognosis for reading be favorable. From among these children, the three selected were those who showed the highest scores in auditory comprehension and in the tests of pre-reading abilities. The tests used included: Wisconsin Pre-Reading Skills Test; Peabody Picture Vocabulary Test; Test of Auditory Comprehension of Language and the Boehm Test of Basic Concepts. Since the project budget provided for only three devices, it was necessary to pick the most promising pre-reading subjects for this testing period. Favorable results from these subjects would justify offering the technique to cognitively less mature candidates. The intent of the project was to leave the device with the child at all times, not only during the training sessions. Because of delays in constructing the machines this has been possible, for these two subjects, only since February. The data reported here are drawn from the first 11 training sessions.

RESULTS

Error Rates

Both subjects have acquired mastery of 24 syllable units in isolation and in combination to reply to questions (the 'no model' phase of training). Both have also used these units to make spontaneous remarks (e.g., one child, in response to his mother's joke, commented "funny mommy" (4 units). Percentage correct on the first try at the 'no model' level for the 24 units are 87% and 82% for the two boys. When self-corrections are added (with no prompt from the trainer), performance is at 97% and 87% respectively. Both subjects have as of February 1 reached the dictation level in acquiring 12 new units (to make 36 total) which include single consonants to combine with syllables to make words. One boy has already begun to make these combinations spontaneously.

Error Analysis

Substitution, omission and order errors are being systematically transcribed for the 'no model' condition. A frequent substitution error pattern involves replacing a two-syllable target (the expected response) by a single syllable whose phonemes are drawn from both the target syllables. In other words, C_1V_1 C_2V_2 may become C_1V_2 or C_2V_1. Errors which are similar to the target but differ in only one acoustic feature are also seen, as has been reported for French users of a phonetic communication board (8).

DISCUSSION

Studies of developmentally nonvocal writers (14) suggest that perceptual salience of certain acoustic features plays a role in the nonstandard spelling of people who have never been able to speak.

More data is needed to determine whether there is a feature preference hierarchy in the sounds the PreSPEEC subjects choose to represent in making substitution errors.

Examination of the data as learning progresses will also allow tracking of sequence errors in syllable and word combinations. Since attention to sequence at the word level is only rarely necessary to comprehend language for practical purposes, it is not surprising that sequence errors show up when the child finally gets the opportunity to produce utterances. Of course in production such errors are much more noticeable than in comprehension, and they elicit negative feedback from others. It will be of interest to see whether sequence comes under better control as there begins to be some utility for the child to attend to it.

Further analysis of substitution errors and of the quality of language produced by the children as they acquire more of the units of the system is planned.

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REFERENCES

1. Gans, B. Physiological and Medical Considerations in Nonvocal Communication. Paper presented at the Symposium and Workshop on Nonvocal Communication, May-June 1979, Tufts University, Medford, MA.

2. McDonald, E. Conventional Symbols of English. In G. Vanderheiden and K. Grilley (Eds.) Non-Vocal Communication Techniques and Aids for the Severely Physically Handicapped, Baltimore: University Park Press, 1977, 77-84.

3. Fourcin, A.J. Language Development in the Absence of Expressive Speech. In E. H. and E. Lenneberg (Eds.) Foundations of Language Development, Vol. 1, New York: Academic Press, 1975, 263-268.

4. Viggiano, J. A View from the Inside. Paper presented at the Symposium and Workshop on Nonvocal Communication, May-June, 1979, Medford, MA.

5. Lenneberg, E. Understanding Language without the Ability to Speak: A Case Report, Journal of Abnormal Social Psychology, 1962, Vol. 65, 419-425.

6. Krashen, . Lateralisation, Language Learning and the Critical Period: Some New Evidence, Language Learning, 1973, Vol. 23, No. 1, 63-74.

7. Lenneberg, E. Biological Foundations of Language, New York: Wiley and Sons, 1967, 125-187, "Language in the Context of Growth and Maturation."

8. Goodenough-Trepagnier, C. Language Development of Children without Articulate Speech. In R.N. Cambell & P. Smith (Eds.), Recent Advances in the Psychology of Language and Mother-Child Interaction, New York: Plenum Press, 1978, 421-426.

9. Goodenough-Trepagnier, C., Tarry, E. & Prather, P. Derivation of an Efficient Nonvocal Communication System, Human Factors Journal, 1982, 24(2), 163-172.

10. Goodenough-Trepagnier, C., Goldenberg, E.P. & Fried-Oken, M. Nonvocal Communication System with Unlimited Vocabulary Using Apple and SPEEC-Syllables. Proceedings of the Fourth Annual Conference on Rehabilitation Engineering, 1981, 173-175.

11. Savin, H. & Bever, T. The Nonperceptual Reality of the Phoneme. Journal of Verbal Learning and Verbal Behavior, June 1970, 9, 195-302.

12. Gleitman, L. & Rozin, P. Teaching Reading by Use of a Syllabary, Reading Research Quarterly, 1973, 8, 447-483.

13. Goodenough-Trepagnier, C. & Prather, P. Communication Systems for the Nonvocal Based on Frequent Phoneme Sequences, Journal of Speech and Hearing Research, 1981, 24, 322-329.

14. Goodenough-Trepagnier, C. Nonstandard Spelling by Developmentally Speech-deprived Individuals: Implications for Phonological Development in the Nonvocal, 6th Annual Boston University Conference on Language Development, October, 1981.

ADDRESS

Tufts-New England Medical Center, Department of Rehabilitation Medicine, 171 Harrison Avenue, Box 1009, Boston, MA 02111

A HIERARCHY OF AUGMENTATIVE COMMUNICATION SYSTEM CHARACTERISTICS USEFUL FOR MATCHING DEVICES TO CLIENT'S NEEDS AND SKILLS

6.12P

A. M. Cook, C. L. Coleman, A. M. Preszler and D. L. Dahlquist

Assistive Device Center

ABSTRACT

A method for relating speaking and/or writing impaired clients' goals and skills to the characteristics of augmentative communication systems has been developed. Clients' goals and skills are assessed and systematically related to identified characteristics through a hierarchial format.

INTRODUCTION

The process of assessing persons with speaking and/or writing impairments for the purpose of recommending an augmentative communication system requires a systematic methodology which includes consideration of many factors. Some general approaches to this problem have been described (1,2,3,4), and there is a general understanding of the need to determine the physical capabilities of the client (5), the cognitive and language abilities of the client (6), and the goals and needs of both the client and those with whom he or she will communicate (7). One area that is often overlooked, however, is the necessity to transform client skills and goals to characteristics of augmentative communication devices in a systematic manner. This paper describes a systematic procedure for determining characteristics of devices that will meet the client's needs and for identifying "candidate" augmentative communication systems based on client abilities and goals.

BACKGROUND

The solution to any problem is easiest and most reliable when the steps toward that solution are logical, orderly and clear cut. For many years, teachers, therapists and engineers have been faced with the problem of matching non-speaking client goals and needs for augmentative communication to an optimum system or systems. The first approaches to solving any problem are usually intutive. This may work particularly well when the individuals solving the problem have had experiences with various clients who had similar types of disorders. The accumulation of such experiences over time may be shared and the success and failure of various techniques evaluated and sorted out. This method, which has frequently been called "clinical intution", has certain disadvantages. The body of knowledge is usually neither organized nor explicit, and it is individualized to each client. This puts the student or professional who lacks experience in that particular area at a distinct disadvantage. It was this state of the art in the area of assessment and matching client's goals and needs to appropriate augmentative communication systems that led us to develop a hierarchial structure for this matching process. This hierarchy is based on our accumulated knowledge and experience, and it is intended to organize the assessment process both for the novice in this field and for the experienced clinician. In both cases it can help to organize clinical intuituion to provide more logical, orderly and clear cut solutions.

METHODS

The hierarchy was developed by devising an orderly assessment based on clinical findings and revising it over a three year period as clinical and theoretical evidence dictated (8,9). The subjects for the research consisted of 42 students between the ages of 5 and 21 years. There were 30 males and 12 females. They included 32 cerebral palsied, 4 trauma, 2 developmentally delayed and 4 other individuals with various types of disodrers.

Both objective and subjective results of the adequacy of the assessment and matching process based on the hierarchy were evaluated (9). Objective measures compared the needs of the client with the features of system provided so that any discrepencies could be noted and the procedures changed to avoid any future mismatches. Subjective measures were obtained by asking clients, teachers, parents and therapists to evaluate various aspects of the match following a period of use and to make adequacy judgements. This information was then evaluated in order to determine any areas of weakness and need for change in the hierarchy.

RESULTS

The hierarchy is shown in Table 1. There are seven levels in this hierarchy: symbol system, physical selection method, cognitive selection method, output format (receiver and user), vocabulary size, vocabulary manipulation, and physical construction. Each of these levels rperesents a class of characteristics available in a communication system. These are arranged from lowest to highest level based on the highest level being the most general and the most inclusive of lower levels, and the lowest level being the most specific and the least dependent on higher levels. Within each category there is also a hierarchy based on the same considerations.

In addition to placing device characteristics in appropriate relation to each other, this hierarchy forms the basis for an assessment (evaluation) of clients. The evaluation must include the gathering of data related to each of the hierarchy categories, and a clear delineation of client goals (9). These data can then be related to devices through the heirarchy described here. Progression from the lowest to the highest level reduces the number of available system options; i.e., the scheme converges to a set of candidates among which there are tradeoffs. Since one system seldom meets all needs, more than one device may be selected and/or the candidates must be prioritized. When they are prioritized, tradeoffs of one feature for another are often necessary. The use of this scheme for any individual provides a framework for decision making, rather than a step-by-step procedure for assessment.

Symbol Selection Method We have chosen symbol system type as the lowest level of the hierarchy because this characteristic is the most limiting in system choice. If an individual requires a picture system, then most printers, word boards, etc. are eliminated. At the next higher level is the use of a symbol system possessing grammar and syntax (e.g. Blissymbols). The nature of this symbol system allows the inclusion of more linguistc functions such as categorization by parts of language, etc. Printing systems cannot, in general, print Rebus, Bliss and other special symbols. Thus, most printing systems are eliminated at this point. The use of whole words is the next level in the hierarchy because clients often have reading skills that exceed their spelling skills. Within the symbol system category, the use of spelling is the most abstract, most generally applicable and encompasses all utterances that can be generated by lower level symbol types. The use of phonemes to generate unrestricted synthetic voice output is taken to be equivalent to spelling.

Given these symbol types, we can relate them to the output characteristics of devices. This serves as the first step in narrowing the choices of candidate systems. For example, simple visual lights in array elements can convey whatever symbol is placed in the element. Other aids such as small portable printers are capable of printing only alpha-numeric symbols. Voice output aids can represent words, spelled letters or phonemes, with input selection via pictures, symbols, words, letters or phonemes. Thus, symbol type directly affects the availability of candidate systems for a given client.

Physical Selection Method. The next most basic characteristic is the physical method by which the client accesses the system. Order within this category is based on the number of independent choices which can be made by an anatomic site or a combination of anatomic sites (e.g., hand, arm, head, chin, leg, foot, etc.). The lowest level is the use of any binary choice. For example, a single switch of any type or a head nod for "yes" or "no" provides one control signal for the person to use in selecting vocabulary or controlling the device.

Arrays consisting of two to five choices are at a higher level because they are more general, and they include the single binary choice as a subset. This level includes any "array" of choices of from two to five items including simple pointing via hand or head pointer (for example) or sets of two to five switches (including joysticks). A new level is defined for arrays in the range of five to ten choices because this includes "numeric" (0 to 9) keyboards. Small numeric keyboards require relativly fine motor control, but can be used in a very restricted spatial location (such as mounted to the arm of the wheelchair) and they do not require a large range of motion. Enlarged numeric keyboards are also available for persons with limited resolution. Full alpha-numeric keyboards (e.g. typewriters) are the most general and flexible of switch arrays. They do, however, require both fine motor control and relativly large range of motion. Keyboards may be activated with the head or toe as well as the fingers.

Cognitive Selection Method. Two basic schemes are used: direct selection and scanning (10). The method of choosing vocabulary that requires the least cognitive skill is direct selection of the desired item. In direct selection all the choices are presented to the user at one time and the user has the physical ability to choose any one element directly. We use this term only for systems in which the entire vocabulary is visible to the user at one time.

Scanning requires the user to make a series of sequential choices that eventually lead to the desired element. Linear, row-column and directed scanning are the most common types. Scanning is cognitively more difficult than direct selection, and it is a more general concept in that it is less dependent on the client's physical capabilities.

Encoding, which may be used with direct selection or scanning, involves the use of a symbol (number, letter, mneumonic, color, etc.) as a code for vocabulary items. The user selects the code rather than directly selecting the element. Encoding schemes are cognitively more difficult than either of the lower levels, and thus require the greatest cognitive skills on the part of the user.

Output Format. Receiver and user output form is the next level in the hierarchy. There are two basic modes by which augmentative communication systems provide this output: visual and auditory. Visual outputs may be either transient or permanent. Transient visual outputs are either single light indicators used in an array, alpha-numeric readouts (including tv-like screens), or selections pointed to on a communication board. Auditory outputs are either simple tones (e.g. an alarm) or voice. Voice output systems may be either pre-recorded messages that are accessed randomly or computer-synthesized speech.

There are two types of outputs in a communication system: one for the user of the system and one for the receiver of the message. Often these are identical, but in many aids they differ in one or more of the following ways: symbol system, size of characters, mode (e.g. words for user, voice for receiver), and existence of "control characters" (e.g. "end of word" marker on a spelling board for user or receiver, memory recall, etc.).

Vocabulary Size. Given the levels discussed thus far, the next choice is the size of the vocabulary to be included. Communication systems may use several different ways of storing the required vocabulary. Permanent vocabulary may be thought of as stored in a series of one or more pages. For a simple communication board or an array communicator, there is only one page of stored vocabulary. This page may contain words, letters, pictures or symbols, and they may be selected in a direct or scanning manner (including code-based). Because a single page provides such a limited set of vocabulary items, many systems have additional pages. For non-electronic aids this results in a book format with each page containing a subset of the total vocabulary. For electronic communication aids, the pages are locations in memory. The pages are accessed by the user through a code which may be as simple as a page number or it may be a category name such as "foods".

Lower levels of the hierarchy directly affect the vocabulary size as well. If the client can use spelling as the symbol system, then the vocabulary available to him or her is not limited by the device. For any lower level symbol system, both the user and the device limit the vocabulary size since it is impossible to store thousands of words or symbols (a minimum functional vocabulary for even a young child) in most augmentative communication systems. Physical selection method also affects vocabulary size. If a single switch is required then selection methods must be geared to efficient retrieval and large vocabularies are difficult to achieve. Similar considerations apply to coginitive selection method, especially in regard to encoding. If the client cannot encode, then the avaialable vocabulary is only what can be displayed at one time. This limits the choice greatly.

Vocabulary Manipulation. Given a vocabulary symbol type and size, required manipulation of that vocabulary can be determined. The lowest level of manipulation is direct symbol selection. Also, one form of vocabulary manipulation is the translation of vocabulary elements from one symbol system to another when the user needs one type of symbol and the receiver needs another. The simplest form is the use of words above pictures or symbols where the "translation" is made directly on the board. Other examples are the use of either words, pictures or symbols as input for voice output devices or text-to-speech systems. The use of control characters such as "print", "enter" or simple markers like "end of word" is at a higher level. Electronic communication aids can employ other forms of vocabulary manipulation. For aids in which scanning is used, speed can be increased by employing a frequency of occurence algorithim. Selection of a single page from multiple stored pages is an extension of the two lower levels since this requires the use of some encoding and the use of control characters.

Correcting erroneous entries and modifying text are other forms of vocabulary manipulation. This may take the form of simply backspacing and obliterating the letter (such as with the some printers) or it may involve the movement of a "cursor" that marks the location in the entered text at which the correction is to be made. In more sophisticated systems, the user may be able to insert characters, words, or whole paragraphs; to delete any of these, or move large blocks of text to new locations.

Physical Construction. The characteristics that are the most general and depend the least on lower levels, and are the most inclusive of lower levels are physical attributes of the system. "Mountability" refers to the flexibility with which the device can be attached to a wheelchair or carried by an ambulatory client. We place it at the bottom of this category because it is the most critical in use. No matter how well a system works in an assessment session, it will not be effective in every day use unless the person has access to it at all times. This is determined primarily by the mountability of the system. Another critical factor in determining how often and how well a device is used is storage requirements. These refer to ease of removal of a lap tray, for example, or the space required to store a device when it is not in use. These two characteristics, in conjunction with all lower levels, determine size and weight of the communication aid. Finally, the color and design (packaging) of the aid depend the least on other properties, and thus belong at the top of the heirarchy.

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REFERENCES

1. Coleman, C. L., A. M. Cook and L. S. Meyers (1980). Assessing non-oral clients for assistive communication systems. J Speech Hearing Disord., 45: 515-526.
2. Lloyd, L. L. (1976). (ed.) Communication Assessment and Intervention Strategies. Baltimore: University Park Press.
3. Shane, H. C. and A. S. Bashir (1980). Election criteria for the adoption of an augmentative communication system: preliminary considerations. J. Speech Hear. Disord., 45(3): 408-414.
4. Silverman, F. H. (1980). Communicaiton for the Speechless . Baltimore: University Park Press.
5. Barker, M. R. and A. M. Cook (1981). A systematic approach to evaluating physical ability for the control of assistive devices Proc. 4th Ann. Conf. Rehab. Engr., 287-289.
6. Meyers, L. S. and C. L. Coleman (1982). Testing non-oral individuals for augmentative communication systems: a symbol system assessment model. Assistive Device Center Preprint. Submitted for Publication.
7. Coleman, C. L. and A. M. Preszler (1982). Philosophy and procedures involved in initial assessment of non-oral individuals. Assistive Device Center Preprint. Submitted for publication.
8. Coleman, C L., A. M. Cook and L. S. Meyers (1982). Enhancing the educational potential of non-oral children through augmentative communication system use. Final Report of project U.S. Department of Eduction Grant #G007902261.
9. Coleman, C. L., A. M. Cook, L. S. Meyers, D. L. Dahlquist and A. M. Preszler. (1983). Matching non-oral subjects needs and skills to augmentative communication system: Results of a three year study. Proc. 6th Ann. Conf. Rehab. Engr.
10. Vanderheiden, G. and K. Grilley (1975). Nonvocal Communication Resource Book. Baltimore: University Park Press.

Table 1. A Hierarchy of Augmentative Communication System Characteristics

Physical Construction
Vocabulary Manipulation
Vocabulary Size
Output Format
Cognitive Selection Method
Physical Selection Method
Symbol System

Assistive Device Center
California State University, Sacramento
6000 Jay Street
Sacramento, CA
95819

6.13P INDEPENDENCE AND SPEED IN COMMUNICATORS

Ernest J. Hernandez - Advanced Instrumentation Systems
Frank Smisson

ABSTRACT

The purpose of a communication device is to provide for effective functional communication and language development for a non-oral individual. Language development, a component of communication, occurs when the environment provides appropiate stimulation for the individual and when certain behaviors are reinforced so that they are more likely to occur again. In communicating with a non-oral individual, the verbal participant frequently "takes charge" of the "conversation" which ultimately resorts to a question-answer session. The non-verbal partcipant's contribution to such an exchange consists of single words. And here again the well-intentioned verbal participant guesses the word having seen the first 2 letters on the communicator output. Such "conversations" do nothing for the developmental skills of the non-verbal. New words and ideas must be expressed and applied with some frequency if they are to take root.

The design of the CRT comminicator, described within, attempted to eliminate and prevent some of the typical "conversations", thus allowing for development of the user via total participation.

INTRODUCTION

The CRT communicator was the brain child of a severe cerebral palsied man, his father and the design engineer. An informal evaluation netted and intelligent athetoid with good vision but little or no finger control. Gross movement was fair and thus, switch selection allowed user comfort as well as practical design considerations. Current use of the Handivoice by Phonic Ear gave the father and son practical experiences regarding limitations of commercially available products. Portability was an absolute necessity required by the father. This sentiment is shared by the design engineer. Communications must be made convenient if frequency of use is to be maintained.

Having a range of options, the father and son decided upon the following major items:

a) Morse Code switch entry
b) Electronic keyer
c) Foot activation switches (two)
d) Audio response
e) Fast access of pre-determined words or phrases
f) Portability

BACKGROUND

Unable to key-in the numeric codes required by the Handivoice, the son used the remote switch entry option. Using a scanning method, the individual presses the remote switch when the desired number appears. Each sound requires a three digit code. Speed is painfully lacking in such a procedure. As expected the Handivoice is a good instrument for the normal to slightly physically handicapped individual, but falls short for the severely physically handicapped for which it was not primarily designed (remote Off-On switch is not standard).

The father had purchased an Apple computer for the son. Its primary purpose was for hardcopy generation. With some basic editing features, it proved helpful. The "error free letter" was now available to the son. He "typed" on it with a head stylus. Although reliable, this system was not convenient due to the head apparatus and the physical location of the system.

The two characteristics father and son wanted most were independence and speed.

MATERIALS AND METHODS

Since the father and son owned an Apple computer, the CRT communicator was designed using the 6502 microprocessor chip (the same as the Apple's). While initially, there were no plans to interface the two, using the same chip would make such plans easier. Below is a list of the major components used:

a) 6502 processor chip
b) 6522 peripheral interface chip
c) 2 LCD alphanumeric displays

d) Voice synthesizer
e) Gooseneck mounting hardware
f) Wheelchair battery

Specifications

The dimensions of the CRT communicator are 10 by 6 by 5 (inches). It weighs 4½ pounds. The LCD displays are positioned one above the other on the 10 by 6 plane. A phonojack for an 8 ohm speaker provides the voice output. The communicator was attached to one side of a gooseneck assembly. The power cable (12 volts and ground) and the footswitch cable (2 miniplugs) ran out the other end of the gooseneck. The gooseneck attachment was mounted on the left side of the wheelchair.

LCD displays

The top display contains the current text. It operates in two modes: Normal and Speech. Switching between the two is via Morse Code selections. The Normal mode is visual only. The Speech mode is visual plus synthesized voice output. The bottom display is the "electronic Communications Board" (ECB). It displays the codes and their associated predetermined words/phrases.

RESULTS

Independence

Independence, by definition, would be achieved when the user could functionally control all "variable" settings.

Off-On switch. This would serve two purposes: 1) allow the user to initiate and 2) save battery power.

Rate setting. The user chose Morse Code as his entry mode. A time delay exists between each "dit" or "dah" to the next. Traditionally, an external potentiometer is used to set this rate, making it inaccessible to the handicapped individual. The CRT communicator incorporates stepped increments or decrements of this rate via Morse Code selection, thus allowing the user to "set his own rate".

Electronic Communication Board. The bottom LCD display eliminates the need for large poster type boards, necessary for listing the codes and their words/phrases.

Portability. Mounted on the wheelchair, the height of the display was such that the user and the verbal participant (standing on the right) could both see it.

Speed

Speed was obtained by providing to the user prepared words and even screen's worth of prepared text.

Menu Coding. Menu Coding is the concept of retrieving pre-determined words/phrases stored in non-volatile memory by much shorter assigned codes. The word/phrase is usually one of frequent use. The selection of the words/phrases takes into consideration:
a) Environment
b) Vocational setting
c) Academic setting
d) Colloquialisms
e) Projected uses

Bascially, the codes are entered instead of the word/phrase desired. After due processing, the word/phrase appears on the output display in the same location where the codes were entered. An example is " /tgtogether/ ". Slashes separate the different entries. The first 2 characters (tg) are the code. The remaining characters (together) make up the word/phrase.

Snap-shots. Snap-shots refer to the process of storing the entire contents of the output display in memory. The contents can be restored at any time. This is valuable in preparing messages or saving the current text in order to "converse" on the spur of the moment.

Menu Code access. For the Menu Coding concept to be of any significance towards speed, its formation would have to be available during the course of writing the desired word/phrase. Certain guidelines were helpful. It was determined that the first character of the code would be the same as the first character of the word/phrase. Only the first 2 characters after a "space" would be tested as Menu Codes. A "space" generated on the top display (text) would clear the bottom display (ECB). Interaction between the displays follows.
a) User generates "space" and clears the ECB.
b) User enters first character on the text display.

c) Time delay associated with switch entry expires.
d) Immediately afterwards, the processor determines this first character and places all Menu Codes beginning with the same 1st letter on the ECB.
e) User can quickly examine ECB for desired word/phrase. Upon finding it, user enters the second character of its code. The word/phrase is then placed on the text display.
f) Immediately after the word/phrase is translated onto the text display, the ECB is cleared. Cycle begins again at step (b).

Step (e) incorporates options for the user. Two user-proven options (A and B) have been utilized, each with advantages and disadvantages. Option A automatically tests each 2-character pair following a "space" as a potential Menu Code. If the test is true, the associated word/phrase is immediately translated onto the text screen. Option B will test each 2-character pair following a "space" ONLY if a "space" is entered after the pair. Option A is faster but care must be taken to avoid Menu Codes that are the beginning 2 characters of a typical word. A bad choice would be "th". Option B allows any Menu Code (hence, more familiarity) but is slower because of the extra "space" needed to initiate the test.

Electronic keyer. This feature allows rapid activation of either the "dit" or "dah" switch by simply holding it down.

CONCLUSIONS

Menu Coding will never dominate any conversation. One can only go around "speaking" in pre-determined phrases for so long. Inherently, initiation will assign them a secondary role whose intent is to keep the conversation apace. Two spin-offs from Menu Coding should be mentioned: 1) the verbal participant usually cannot guess the word due to the odd combinations of codes which in turn, gives the non-oral person more control of the conversation and 2) having NEVER expressed themselves quickly, the physically handicapped individual fully embraces the concept.

Regarding Morse Code, speed will result only when the user masters the electronic keyer, which in turn depends upon the quality of the switch assembly. Switch "fitting" is an art in itself and quite time consuming, but there's no shortcut for speed and accuracy.

The snap-shots have been effective in initiating a forum for different subjects. Plans are in order to increase the number available to the user.

As expected, lack of independence provided for poor consistency. The prototype CRT communicator has a separate display which must be anchored each day or depending upon the activity within the day. Sometimes it was attached and at other times not. The user would resort to the "old way" of communicating not wanting to inconvenience staff or his teachers. (See Abstract)

The microprocessor-based system proved flexible. Changes are simple. The ROM (read only memory) chips are removed; updated, and re-inserted. Software driven designs are a must.

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For information concerning the CRT communicator contact:

Advanced Instrumentation Systems
P.O. Box 3255
Port Arthur, Texas 77640

Frank Smisson
1607 W. Michigan
Midland, Texas 79701

DEVELOPMENT OF A COMPUTER-AIDED SYSTEM FOR PRESCRIPTION OF NON-VOCAL COMMUNICATION DEVICES: A PROGRESS REPORT

M. J. Rosen
Department of Mechanical Engineering, Massachusetts Institute of Technology
C. Goodenough-Trepagnier
Department of Rehabilitation Medicine, Tufts-New England Medical Center

BACKGROUND

A contract research project funded by the National Institute of Neurological and Communicative Disorders and Stroke to develop procedures for prescription of non-vocal communication systems has been underway for six months (as of January, 1983). The purpose of this paper is to outline the structure of the prescription system and present the status of those aspects of the project in which development has taken place.

The proposed prescription procedure is characterized by the following key features, in which it will differ from current clinical practice:

- The procedure will be systematic. The goal is to develop a standard sequence of steps and decision logic for assessment, formatting assessment results, comparison to device characteristics, and identification of an optimal prescription.

- The procedure will embody a consensus of present clinical opinion. The goal is to develop an "expert system", i.e., one which provides implicit access for any clinician to the opinions and experience of acknowledged clinical experts.

- The prescription system will be quantitative. Comparisons among devices for a given patient will be based on computation of cumulative scores representing the objective and perceived value of each candidate device to a potential user.

- Because of the intended exhaustiveness of the procedure and the generally large number of possible combinations of device and interaction mode for a given patient, the procedure will be computer-assisted. This is not only computationally essential but also the only practical means for making accessible a compilation of device characteristics which is current, uniformly formatted and scaled, detailed, and exhaustive.

- Computer-guided aspects of the scheme will be interactive. For example, a clinician wishing to determine the reasons for a device's rank in a list of aids generated by the prescription system will be able to enter a command which causes graphic display of the relationship between characteristics of the patient and the particular device.

- The procedure will need to be completely general, i.e., not device-limited. The intent is to develop a scheme which will embrace the full range of existing aids as well as those yet to be developed. More important, the procedure will provide a basis for testing the effect of altering the device characteristics on user-device match scores.

- The cumulative scores mentioned above, representing the user-device match, are intended to be predictive. A validation study in the final year and pilot studies before that will be carried out to determine statistically whether the hypothetically appropriate scores do in fact predict communication performance and satisfaction.

The project accepts several limitations on its present target population in the name of reducing a nearly unmanageable task to practical proportions. We are dealing with the adult non-vocal population with adult-onset impairment. Further, we are screening for near-normal (defined as "sixth grade level") language and cognitive abilities.

STRUCTURE OF PRESCRIPTION SYSTEM

In the most general terms, prescription of a non-vocal communication device requires assessment of the potential user and comparison of his or her assessment data to the characteristics of available devices, leading to selection of one. Two features of this problem make it difficult. First, description of the person is extremely multi-dimensional; and secondly, one wishes to select not just a device that the patient can use but the device which is optimal for the individual. These features motivate the development of a procedure which, as noted above, is systematic and computer-assisted. The structure of our procedure (specified in some respects in the original RFP from the NINCDS) is outlined below.

The match between a patient and a potentially useful NVC device is characterized by two cumulative scores defined as Ease, E, and Benefit, B. A decision as to which device to prescribe is based on determination of which device provides the highest value -- for the particular patient -- for the product of these quantities. Calculation of E and B for each user-device combination is based on mathematical comparison of two pairs of numerical profiles which characterize the person and the device. The values of the components of these profiles are obtained from person assessment procedures conducted (ultimately) when the patient is seen in the clinic, and from device assessment which will be undertaken during the present project.

The patient is characterized by an Abilities profile and by a Needs and Preferences profile. An important distinction between this procedure and current practice is implicit in the profiling approach. The clinician assessing a patient may presently find it expedient to keep in mind a small number of particularly well-known (or locally available) aids while surveying the person's abilities in the hope that it will become apparent that a particular aid might be used successfully. In the proposed procedure, the goal is to undertake assessment of the user's Abilities and Needs to derive, in effect, a model of the person, in a standardized form, for computer-aided comparison to any existing or future device.

Devices are described by two profiles, one specifying the Operational Requirements the device places on the user, and the other defining the Features and Functions the device provides to the user. Comparison of user to device consists of relating the user Abilities profile to the Operational Requirements profile and the Needs and Preferences to the Features and Functions. This pairing is intuitively correct. To use a device, each Ability must at least be equal to the corresponding Operational Requirement. But in addition to this obvious criterion for exclusion, a device ought to be easier to use to the extent that the individual has a surplus of Abilities beyond the Requirements of the device. The proposed Ease score noted above will, in fact, be calculated as a simple weighted sum of the differences between Abilities and their corresponding Operational Requirements. Although the details of calculation of a Benefit score differ from computation of Ease, the concept is the same.

Among the most important variables in prescribing a device is communication rate. This does not readily fit the profile matching scheme since rate is neither an element of the user profiles nor of the device profiles. It is clearly a property of each user-device combination. Training and testing of a patient with each candidate device to determine communication rate empirically is clearly not feasible. The alternative presently under development is predictive estimation of an individual's rate with each device from data taken in an abstract motor assessment task combined with device-specific information. A detailed outline of this procedure may be found in Demsetz et al., 1983.

ABILITIES ASSESSMENT: MOTOR EVALUATION

A task to which considerable time has been devoted in this project is the development of a protocol for assessing motor function of a patient and transforming the assessment data into a uniformly expressed motor Abilities profile. While this is only a component of the overall Abilities profile, it is expected to have major impact on the Ease score, i.e., on ease of device use, relative to other Ability categories. A great deal of work remains to be done in this area but some concepts likely to be incorporated in the final version of the prescription procedure have emerged.

In our planning sessions to date, a clear distinction has emerged between traditional motor assessment as conducted by physical and occupational therapists and the kind of assessment required to generate the very specific sort of model of a patient needed for comparison to devices. In traditional assessment, the goal is to generate an exhaustive description of residual motor abilities, in particular the ways in which they are limited or distorted by pathology. It would include, for example, joint-by-joint cataloguing of range of motion, tables of the type and degree of tone disorders found in each body part, and detailed observations of reflexive postural reactions to voluntary movement. While it is certainly true that this information has strong implications for the use of devices, it is the operational effect of these disorders whose measurement is needed for comparison to device operational requirements. It is impossible to conceive of assessing a device to calculate the Requirement it imposes for freedom from the Asymmetrical Tonic Neck Reflex. On the other hand, a profile which expressed the net effect of a patient's movement impairment in terms of just four variables -- range of motion, strength, speed, and accuracy -- would incorporate assessment data in precisely the economical, functionally-oriented form needed for profile comparison.

Clearly, the values of these assessment variables will be strongly dependent on three parameters: 1 - which body part is being assessed, e.g., right hand, left foot or head; 2- what actuation variable is being tested, e.g., movement, isometric force, or processed myoelectric activity; and 3- what position the patient is in when assessed, e.g., reclining, sitting or standing. In effect, each combination of these parameters is a "sub-patient", a different person from the standpoint of assessment. This is particularly true in the presence of strong reflex interaction among voluntary movement, posture and tone.

The number of sub-patients to be assessed, even for a severely impaired person, can be impractically large. While exhaustive survey of motor Abilities for all position/body part/action combinations is not feasible, "common sense" exclusion of any from consideration by-passes the profile-matching concept as the basis for selection and may miss an advantageous user-device match. If motor assessment is to be completed in a reasonable time, criteria are needed for halting survey of sub-patients and for identifying the "best" of those tested for more detailed assessment. Clearly, the assessing clinician will want to assess in a particular order, an order which could be expected to uncover functionally superior combinations earlier rather than later. We propose to establish this "natural hierarchy" on the basis of data taken from normals, and on the basis of present clinical opinion.

A well-defined index for "functionality" will be needed for the purpose of rank ordering position/body part/action combinations in a natural hierarchy, and to provide a means for the clinician to select the optimal combinations from among those surveyed on a patient. A concept presently being considered uses computer assistance to help the clinician decide when to halt the survey of combinations, while minimizing the risk that potentially useful combinations will be omitted. The computer assistance will take the form of an on-line comparison of the values of the four variables mentioned above: range of motion, strength, speed and accuracy, for each combination, to the Operational Requirements of a representative set of devices. This approach assures that decisions on whether to carry out detailed assessment of some position/body part/action combinations are grounded in the potential usefulness of the combination for device operation. Inclusion among the set of devices used here of research prototypes which are seen as representative of trends in device design protects the assessment procedure from becoming limited by traditional modes of device operation.

INTEGRATION OF USER AND DEVICE PROFILES

The Calibration Problem

In assessing devices, certain quantities are measurable and constitute a complete characterization of each device. In the present context we will refer to these as device Parameters. These Parameters cannot, in general, be used directly to form the Operational Requirements profile. Each Requirement may be a function of several Parameters and a basis is needed for calculating one from the other. We refer to this as the calibration problem. An example is the Operational Requirement for code learning, relevant for encoded aids. While one cannot directly measure this quantity, it may be expected to vary with at least three Parameters -- the number of language units for which codes must be learned, the number of keys on which these units must be encoded, and some measure(s) of the mnemonic character of the code.

Paralleling the calibration problem is the need to identify, or to design from scratch, assessment instruments to be administered to patients to establish Ability scores. The scaling of an Ability item must be consistent with the corresponding Operational Requirement. In some cases, the Assessment reduces to something obvious and trivially simple such as the Snellen Test (eye chart) for visual acuity. More generally, there will be a need to establish through human experimentation that the score on some hypothetically appropriate test is an appropriate measure of an Ability. In fact, the combined scores from more than one instrument may need to be combined to provide a measure, for example of code-learning Ability. This is an analog to the device calibration problem.

Conceptually, it appears that a two-part study is needed. In the first part, multiple human subjects would be given the proposed assessment instrument(s) and also tested for performance with a non-vocal communication device (perhaps computer-simulated) chosen to be particularly demanding in terms of the Ability of interest. Data would be analyzed to confirm a correlation between scores on the assessment instrument(s) and a communication performance measurewhich reflects the Ability. To establish the Parameters which influence the corresponding device Operational Requirement, the second part of the study would utilize a subject population whose assessment scores reflected a nearly constant Ability level. Communication performance would then be studied for a range of simulated devices which differed only with respect to Parameter(s) expected to influence the Operational Requirement. If the data confirms a relation between the varied Parameter and the Operational Requirement, it should also provide a form for the calibration formula.

Formalism For The Needs - Features Match

The match between an expressed patient Need and device Features is characterized by a pyramid of implications. In other words, each Need implies multiple alternative device Features which could meet that need. This is true because questions that a patient could reasonably be expected to answer cannot be expressed in the narrow concrete terms in which devices are described. Instead, he can be expected to describe Needs in global functional terms. For example, the assessing clinician would not expect answers to questions like "Do you require an illuminated control interface and language menu and high brightness and color contrast of menu characters against their surround and/or a small number of control switches easily identified by placement or texture?" By contrast, one would ask "Do you expect to have to use your device in dimly lit conditions?" Asking the former, feature-oriented type of questions amounts to asking the patient to function as a designer by predicting the technical implications of functional needs.

The standard three-level engineering design formalism, i.e., Needs→Specifications→Features, is a useful organizational paradigm for developing a list of the combinations of device Features which can meet user Needs. The example noted above illustrates these three hierarchical levels:

Need -- To use device in dim illumination.

Specifications -- a: Availability of output display to user and receiver perception; and
b: Availability of control interface and language menu to user.

Features -- a: 1. Illuminated or self-luminous display; or
2. Speech output.

b: 1. Illuminated menu and interface; and
2. Optimal color and brightness contrast;
or
3. Small number of switches recognizable without vision.

Conceptually, the boundary between device description and user need description falls between Specifications and Features. In terms of profile matching, it will be necessary to prepare a Features profile for each device which may be compared on a one-to-one basis with a user's functional Needs profile.

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REFERENCES

1. L. A. Demsetz, et al. Prediction of Communication Rate Preliminary Studies. Submitted to the 6th Annual Conference on Rehabilitation Engineering, San Diego, CA, 1983.

Massachusetts Institute of Technology, Cambridge, MA 02139

7.1 THE CONTOUR-U CUSTOMOLD SEATING SYSTEM

Michael W. Silverman C.O. Oscar Silverman C.O.

Pin Dot Products
P.O. Box 642 Northbrook, Illinois 60062 (312) 975-3900

ABSTRACT

We have develped a seating system using a set of custom-moldable cushions along with pre-fabricated hardware to provide the client the benefit of proper positioning in an efficient manner.

INTRODUCTION

Last year at the RESNA meeting in Houston, we presented our Contour-U customold seating system to the society. Here we present a follow-up report on the further development of our seating system.

Because of the interest shown at last years meeting, upon our return to Chicago we plunged fully into developing our prototype system into one that could be used effectively in the field. This led us to a re-design of our major components, the seat and back shell, and the creation of a line of optional accessories necessary in the proper positioning of our clients. These accessories include a head rest, neck ring, side support, hip blocks and leg rest.

We then designed and built a molding frame, which enables the clinician to simulate the desired seating position along with all the outside forces acting on the client for evaluative purposes. The molding frame then allows for creation of a mold which can be used to reproduce the contours of the client and angles of position for use in a definitive seating system.

BACKROUND

The benefits of proper positioning for wheelchair confined clients has been well established. Around the country, different people are using different techniques to properly position their various clients. Some commercial seating systems have been developed to position general populations of disabilities but for the severely involved only a custom-made seat would work. The problem with the custom-made seats is that they require qualified craftsman to fabricate these devices, and they are also labor intensive. These two factors operate together to produce a seat which is expensive to produce. Also, when the person who does the evaluation is not the same as the one who fabricates the finished seat, the results are sometimes inadequate.

The Contour-U customold seating system overcomes many of these problems. Its secret is a custom-molding technique that is based loosely on the concept of the bean-bag chair. A mold is taken of the patients body, so the finished product fits like a glove, mirroring the precise contours of the person who will be occupying it. Made of vacuum-formed vinyl and polyurethane foam that is seamless and completely washable, each seat is a two-piece "chair" with separate seat and back cushions. This allows the system to be adjusted to the exact angle the individual needs and to "grow" if the occupant is a not-yet-mature child. The Contour-U system is also quite versatile. It can be used in any wheelchair from twelve to twenty inches in width, as well as Mclaren and Pogon strollers. Or, with the turn of just a few knobs it can be removed for separate use as a car seat, a feeding chair or a seat for watching TV on the couch or the floor. The molds can be taken by the same clinican who evaluates the client, or in the presence of the specialist at the time of evaluation. The finished seat is fabricated on a central fabrication basis, to keep costs low and quality high, and assure that the techniques are being properly applied.

THE CONTOUR-U MOLDING FRAME: DIRECTIONS FOR TAKING A MOLD

The molding frame is a device used to simulate the optimum seating position for your client. It consists of basically three moving parts, a seat length adjustment, back to seat angle adjustment, and a variable degree for the angle of seat tilt.

STEP ONE: EVALUATING THE CLIENT

The way to begin is to ask the client, or person who cares for your client what kind of problems are arising because of improper seating. In other words, what would they like to see the seating system accomplish? Only a small amount of correction can be achieved, the exact amount varies for different people. Usually it is best to try to accommodate any deformities in attempting to place your client in a functional position. Although most of the precise evaluation as to seating position and shaping is to be done while the client is in the molding frame, this is the time to decide on what components will be used.

COMPONENT DESCRIPTION

The basic seat is composed of a seat and back shell, two growth links and four quick-disconnect linkages which attach the Contour-U to the wheeled base. When ordering the seat on a central fabrication basis, also included are the custom molded seat and back cushions, and a seat belt attached at 45 degrees. The cushions have a total depth of just under four inches, including padding. This means that the depth of the molded area cannot exceed three and one quarter inches, in most cases.

1. HEAD REST The head rest is the most popular of the Contour-U options available. It is used in most cases when the client has some head control as an extension stop, or to allow the patient to relax occasionally. The head rest is only incorporated into the custom molded back section when the client has absolutely no head control and is not expected to grow very quickly. The use of the optional head rest allows for infinite and precise positioning at the time of delivery.

2. NECK RING The neck ring is similar to that developed by the Rehabilition Engineering Center in Memphis for use in seating children with cerebral palsy. It gives some support to the occipital region of the head and allows limited rotation in attempt to inhibit the primitive neck reflexes many of these children experience. It uses the same hardware and has the same adjustments as the head rest, which allows the two to be interchanged easily at the time of final evaluation or delivery.

3. SIDE SUPPORT The side support is used when the available depth of the back cushion will not adequately control the client's spine. It is a foam covered piece of malleable aluminum, which can be independently positioned at the exact spot necessary at the time of delivery. It incorporates a special feature which allows the support to swing-away for easy entry and exit although it always returns to the proper, preset position.

4. HIP STABILIZATION BLOCKS The hip stabilization blocks are used when the available depth of the seat cushion will not adequately control the client's pelvis. They are basically a block three inches high and three inches wide, and come in seven and ten-inch lengths. With many children and some adults they can also be used as arm rests. They are also completely adjustable.

5. LEG REST The leg rest assembly has a fixed 90 degree angle at the knee and ankle and is adjustable in length. It attaches directly to the seat with an easily detachable bracket. It is twelve inches wide and accommodates both feet with a single piece. The leg rest is intended mainly for use with children, as adults can usually use the leg rest supports that come with the wheelchair. Special foot pieces can be adapted to provide for precise placement of foot position.

DETERMINING THE SIZE SHELL TO USE VS. WHEELCHAIR FRAME

The aluminum shells come in four different widths. The 12 3/4 inch wide frame will fit the Maclaren or Pogon stroller, or the 14 inch wheelchair with the ability to recline between the upright bars. The 14 3/4 inch size will recline between the bars on a 16 inch wheelchair, 16 3/4 for the 18 inch chair and 18 3/4 for the 20 inch chair. The 16 3/4 inch shell can be used on a 16 inch wheelchair but you will not be able to recline the back section past vertical, unless you go to a reclining or semi-reclining chair. The same is true for the other sizes.

STEP TWO: SETTING UP THE MOLDING FRAME

With the back of the molding frame in the fully reclined position, turn on the vacuum and evacuate some air out of the back section, and work the beads so that they are evenly distributed. With the vacuum still drawing and the beads at a "bread dough" like consistancy, preshape the back section of the mold to accommodate that of your client. Lock on the vacuum to stabilize the beads and set the back to seat angle as far foward as possible.

Take a measurement of the patients seat length, measuring from the back of the clients buttocks to just behind the knee. If there is a leg length discrepancy, the molded seat can be made with an angled front to accommodate discrepancies of over one inch. In this case, set the molding frame to accommodate the shorter leg. Set the correct distance on your molding frame, measuring from the front of the back section to the front edge of the seat. By turning the crank behind the back of the molding fixture, the molding frame can be adjusted from ten to twenty inches in length. After the length has been set, adjust the back to seat angle to that predeterimed during the evaluation, and adjust the degree of seat elevation as well.

The Contour-U customold system allows you to adjust the back to seat angle and the degree of seat elevation at the time of delivery, and at anytime thereafter when deemed necessary. The purpose of adjusting the angles when the mold is taken is to allow for a simulation of the final seating position, and to decide if any special growth links or attatchment brackets are to be ordered. The normal growth links allow for back to seat angles of between 75 and 105 degrees. The normal attachment brackets allow for 0 to -25 degrees of seat reclination.

STEP THREE: TAKING THE MOLD.

Once the patient is seated properly, with their hips flat against the back section, check the seat length measurement. Note for any prominent tendons while fine tuning the seat-length adjustment. After carefully placing your client in the molding fixture, slowly draw some vacuum and starting from the hips, begin to work your way foward. Mold the beads next to the patients thighs, forming a ridge at the border of the molded area and the level surface of the untouched beads. The depth of the molded section cannot exceed three inches. Will you be able to control the pelvis using the available depth of the cushion? If not you may have to use a pair of hip stabilization blocks. It is imperative to get the pelvis stabilized to be able to exert any control at all on the spine. It is always preferable to have the mold be to deep than to shallow. Form a pummel at this time if necessary, and lock on full vacuum when the mold is satisfactory.

When working on the back section, it is important to keep in mind that as you loosen up on the vacuum, the polyethylene beads will have a tendency to drop. So loosen up just enough to make the bag moldable, and form the back section as you did with the seat, with a ridge at the border of the molded section. The depth of the contour cannot exceed three inches. When looking at the spine, use your hands to simulate side support positions using a three-point pressure system. Working your way up the spine, mold in enough clearance to allow for full shoulder movement. By inserting your fingers through the windows in the back of the molding frame, you can check for total contact along the back section.

Once the client is believed to be positioned satisfactory, remove the client from the device and review the remaining mold. Is the shape of the patient visible in the back and seat sections? Do you have the control and relief where it is necessary? Is there a clearly defined ridge defining the border of the molded section? Now is the easiest time to change the mold. If you are unsure if you could seat your client better by altering the mold, TRY IT! This is the beauty of the dilation-bag approch to molding, the ability to change the shape as often as necessary before the plaster mold is taken.

TAKING THE PLASTER IMPRESSION

Once the mold is finished, introduce full vacuum and move the back of the molding frame backward an inch or two, and carefully recline the back section as far as possible, being careful not to crimp the latex bag. Lock out the molding frame in this position and you are ready to take the plaster impression. The impression is taken using six to eight layers of plaster splints. Lay the splints down evenly and work them in well to get a good positive impression of you clients negative mold. When the splints have dried, draw a center line vertically through the back and seat sections, to insure proper alignment. Allow the molds 24 hours to dry before packing them for shipping.

PLASTIC CHECK SHELL AND DELIVERY PROCEDURE

The molds are then modified to give the desired result. This gives you a chance to smooth out and balance areas where the mold was imperfect. This is a necessary step as it is next to impossible to take an absolutely perfect mold. We do offer a central fabrication service to modify the molds, just ship the molds to us and within two to three weeks you will receive a polypropylene check socket and will use this to do a check fitting of the contours of the seat and back sections. Use this check shell to determine if the mold and modifications were done properly. Check the length of the seat and height of the back for a proper fit. Mark clearly with a grease pencil any areas where further modification is required and send along detailed notes for these modifications. Upon return of the check shell to our facility, your completed Contour-U seat will be delivered to you within ten days. The hardware is also available if you plan to make the cushions on your own.

CONCLUSION

As of January 1983, We have delivered 38 Contour-U seating systems, with only one failure. This failure was due to improperly shaped cushions. The client was re-molded and is now awaiting delivery. One of the beauties of the system is that, in the case of ill-fitting or out grown cushions, only the cushions need to be changed, all of the mechanical (expensive) parts can be re-used as long as the client stays in the same width base.

COMMERCIALIZATION PROCESS FOR A RESEARCH AND DEVELOPMENT WHEELCHAIR CUSHION

Hugh O'Neill, Rehab. Engineer and Donna Politi-Meeks, OTR
Children's Hospital at Stanford, Rehabilitation Engineering Center
Inder Perkash, M.D.
Veterans Administration Medical Center, Palo Alto, California

INTRODUCTION

Development and clinical evaluation of a new wheelchair cushion was accomplished under a Veterans Administration research grant (1). Upon completion of the clinical evaluations manufacturers were solicited to produce and market the cushion commercially. This new cushion, designated the Veterans Administration Seating Interface Orthosis for Paraplegics (VASIO-P), is designed to selectively redistribute the weight-bearing forces away from the osseous points and onto the more tolerant posterior thighs and trochantors. The cushion which was developed in the research project was found to be effective in reducing the sitting pressures to acceptable levels for 79% of all subjects tested with thoracic lesions and cauda equina injuries. The dedication of the commercial producer to retaining this success ratio in the commercial version of the cushion was an important point in the selection process.

During the clinical evaluations of the original VASIO-P, several factors which limited the practicality of the cushion were uncovered. These included:

1. Difficulty in transferring on and off of the cushion. The primary reason cited by the subjects was the height of the abduction pommel.
2. Failure of the waterproof coating. The waterproof coating which was used in the perineal recess tended to crack and separate after three to six months, depending upon usage. Failure of the waterproof coating not only allowed the cushion to absorb moisture but also to retain odor.
3. Durability. The cushion began to loose some of its support characteristics after six to 12 months of usage.

In addition, it was felt that some minor changes in the cushion materials would help to alleviate high pressure areas when an individual mispositions him or herself laterally on the cushion. At the time that the manufacturer was being selected these problems appeared as minor. It was believed that the necessary changes could be easily incorporated into the commercial version without compromising the pressure relieving characteristics of the original cushion. In fact, four design iterations of the commercial cushion were eventually produced and clinically evaluated before the cushion was considered acceptable.

BACKGROUND

The original cushion, developed under the research grant (Figure 1) was fabricated of a two-part polyurethane foam of two pound density. The cushion incorporated two inserts of ethafoam-220 which were shaped and then molded into the cushion beneath the trochanters and posterior thighs. These inserts aided in transferring the sitting forces from the ischial tuberosities to the sub-trochanteric area and posterior thighs. The cushion itself was contoured with a recessed area beneath the perineum and the ischial tuberosities. This recess further reduces pressure beneath the ischii and allows for greater air flow through the perineum for decreased humidity and temperature. An abduction pommel was incorporated as an integrally molded part of the cushion. The subjects in the original study commented positively on the effect of the pommel on their posture and appearance, however 66% of the respondents reported that the pommel increased the difficulty in transfers.

Tumble Forms, Inc. was selected as the manufacturer of the commercial cushion. Their proprietary waterproof coating was seen as an answer to the problems of cleanliness and odor retention. Their first prototype (Tumble Forms I) featured a reshaped abduction pommel and an overall decrease in cushion thickness of one inch. This cushion also utilized a softer foam for the inserts in place of the ethafoam. Clinical evaluations with this cushion showed that the insert material was too soft and did not provide sufficient support beneath the trochanters.

The modifications which were incorporated into the second version (Tumble Forms II) were determined after a week of experimentation. The research team and the manufacturer's representative cut a void in the cushion and experimented with the placement, shape and type of foam for the new insert. Production versions of these cushions were then produced and clinically evaluated.

The final version of the cushion (Tumble Forms IV) was made 3/4" thicker than the previous versions. This was done by decreasing the amount of the contour on the base of the cushion in order to create a flatter base. The base is now contoured to more accurately fit the sling of most wheelchair seats.

METHODOLOGY

The Tumble Forms cushions were evaluated by subjects drawn from the inpatient and outpatient populations at the Spinal Cord Injury Service, Veterans Administration Medical Center, Palo Alto. The subjects were all adult males with either thoracic level lesions or cauda equina injuries. No attempts were made to preselect the subjects.

Pressure measurements were taken beneath the bony prominences on each subject while they were seated on the Tumble Forms cushion. The Scimedics Pressure Evaluator was used to record pressures beneath the coccyx, ischial tuberosities, trochanters and the posterior thighs. These pressure measurements were used as an objective indicator of the effectiveness of the cushion and as an evaluation tool to help determine where improvements should be made. Subjects who exhibited pressure readings less than 80 mmHg beneath the thighs, 70 mmHg beneath the trochanters, 65 mmHg the ischii and 20 mmHg beneath the coccyx were given the option of remaining on the cushion. Those subjects who elected to remain on the cushion were then followed to assess its durability and overall performance. In order to evaluate the effectiveness of the Tumble Forms cushion compared to the original cushion pressure measurements were also taken with the subjects seated on the original cushion whenever possible. Time limitations sometimes prevented this additional data from being gathered, particularly in the case of outpatients. Nevertheless, this comparison was considered essential in eliminating the influence of individual physique on the data for the limited sample which was available.

RESULTS

The results of testing are presented for only three of the four iterations of cushions produced by Tumble Forms. The third cushion (Tumble Forms III) was recognized immediately as being inadequate and only limited testing was done with it. Versions I, II and IV represent the major revisions of the cushion.

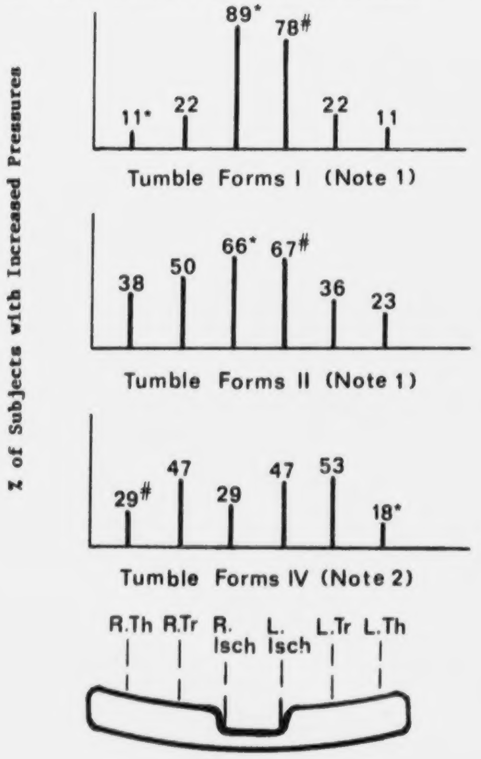
The percentage of the subjects whose pressure readings were within acceptable limits is presented in Table 1 for each version of the cushion. The percent effectiveness of the final version of the Tumble Forms cushion (76%) is very near that demonstrated by the original cushion in the research study (79%).

Table 1.CUSHION EFFECTIVENESS (PRESSURES)

	TUMBLEFORMS			VA
	I	II	IV	Research Cushion
Subjects	12	26	29	66
% Effectiveness	42%	31%	76%	79%

The comparison of the subjects performance on each version of the Tumble Forms relative to the original cushion is shown in Figure 2. The chart shows, for each anatomical site, the percentage of the subjects who exhibited higher pressures while seated on the Tumble Forms than they did while seated on the original cushions. This difference is significant at the ischial tuberosities for the Tumble Forms I and II. However there is no significant difference in the performance of the Tumble Forms IV relative to the original research cushion at the ischial tuberosities and trochanters. The lower pressures beneath the thighs on the Tumble Forms IV is significant. This is because the Tumble Forms cushion is thinner than the original cushion and the footrests were not repositioned lower during testing to accommodate this. Had the footrests been properly positioned we would expect to see an increase in weight bearing beneath the posterior thighs and a further decrease in pressure beneath the ischii.

Figure 2. COMPARISON OF PRESSURE REDUCTION ON TUMBLE FORMS RELATIVE TO RESEARCH CUSHION



Note

1. Pressure reduction beneath the Ischial Tuberosities is significantly less (*p less than or equal to .01; #p less than or equal to .05) with Tumble Forms I and II relative to the Research Cushion.

2. No significant difference in pressure reduction beneath the Ischial Tuberosities and Trochanters for Tumble Forms IV and the Research Cushion.

DISCUSSION

The goals of the research project were to develop a new cushion which would:

1. Redistribute the sitting forces to the more tolerant areas of the sitting surface,
2. Provide a stable base to promote a proper pelvic-spinal alignment, and
3. Be effective for the majority of the spinal cord injured population.

The original cushion which was developed under the research grant did meet these goals; however, it presented some problems with practicality.

These problems (transfers, cleanliness and durability) appear to have been resolved in the commercial version (Tumble Forms IV) while retaining the effectiveness of the original cushion.

The depth of the peri-ischial recess in the original cushion was maintained in the Tumble Forms versions. This recess and the effect of the cushion inserts are the key elements in redistributing the sitting forces. In the Tumble Forms I the lack of trochanteric support due to the softness of the insert material was clearly responsible for the high ischial pressures which were recorded on this cushion.

In the case of the Tumble Forms II however, where the inserts had been made of a firmer material, the cause of the high ischial pressure was less obvious. Eventually it was determined that the excessive contour on the base of the cushion was causing a hammocking effect of the coating on the cushion. The extent of the contour of the base of the cushion was greater than that of most slings on the patient's wheelchair. When the subject sat on the cushion he would flatten the sides of the cushion, thereby stretching the coating across the peri-ischial recess and also decreasing the effective depth of the recess. This was resolved by reshaping the base of the cushion to decrease the contour and provide a better fit with most sling seats. Although this added approximately 3/4" thickness to the sides of the cushion, the actual height of the individual in the wheelchair is unchanged since the thickness of the cushion beneath the ischial tuberosities is unchanged.

The subjects who were evaluated on the cushion consisted solely of adult spinal cord injured males. Further testing will need to be accomplished outside of the Veterans Administration system to assess the effectiveness of the cushion with females and adolescents.

CONCLUSION

Development of the cushion for paraplegics is now complete. The process of transferring the research product to a commercial one spanned 12 months. During this time three essentially new cushions were designed and clinically evaluated. This emphasizes the importance of the manufacturer's committment to maintaining the integrity of the research product while making it commercially feasible.

The project is continuing to develop a cushion for use by quadriplegics. In this case the cushion which is being developed under the research grant will be produced by the same manufacturer from the beginning. The cushion which is developed should then be ready for commercial distribution without modifications and the need for additional testing.

ACKNOWLEDGEMENTS

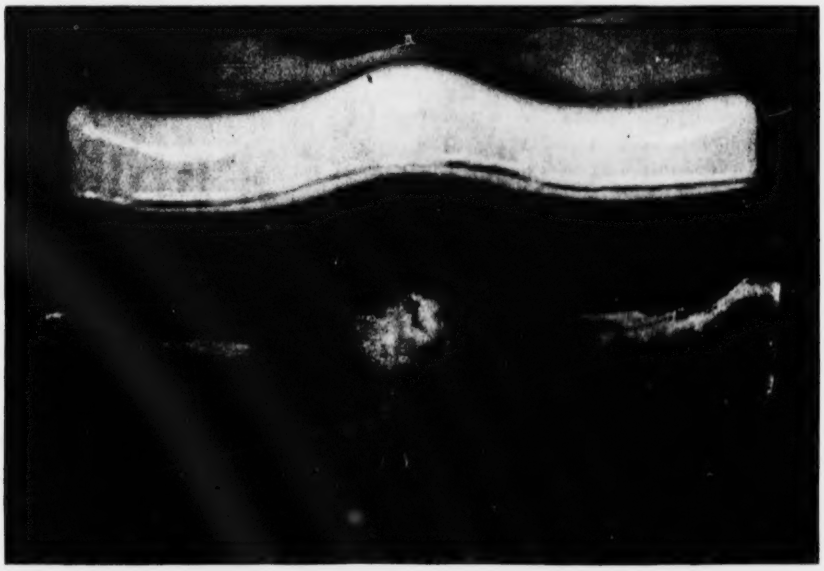
This work was performed under a contract with the Spinal Cord Injury Service, Veterans Administration Medical Center, Palo Alto, California, through a grant from the Veterans Administration Central Office, Rehabilitative Research and Development Service.

We wish to thank Tumble Forms, Inc. for their cooperation and dedication during development of the commercial version.

REFERENCES

1) Perkash, I., Pasillas, R., Politi, D. "Progress Report III-Seating Systems for Body Support and Prevention of Tissue Trauma", Rehabilitation Engineering Center, Children's Hospital at Stanford, December 1980.

Figure 1. COMPARISON OF TUMBLE FORMS II (TOP) AND ORIGINAL RESEARCH CUSHION



7.3

THE SIMPLE WHEELCHAIR INSERT: A WHEELCHAIR-BASED SEATING SYSTEM FOR MILDLY-INVOLVED CEREBRAL PALSIED CHILDREN

Richard N. Holte, MSc.
Children's Hospital at Stanford, Rehabilitation Engineering Center
Palo Alto, California

ABSTRACT

This paper describes the design objectives and methods for a modular wheelchair-based seat for mildly involved cerebral palsied children.

INTRODUCTION

The purpose of the project was to develop a low-cost, wheelchair based insert for cerebral palsied children with mild quadriplegic involvement, in the seven to 10 year age bracket. Nearly all commercially available inserts are not specifically designed for this group of children. The moderately involved child requires relatively less postural support and restraint than is commonly offered, but more freedom in mobility for transferring and self-propelling a wheelchair. This disparity between the child's needs and the features offered by the commercially available systems, is further aggravated by the relatively high price of between $800 and $1200 for commercially available insert systems.

THE DESIGN OF THE SIMPLE WHEELCHAIR INSERT

The design of this device was started by considering the needs of the user in seating, mobility and equipment management. A desired posture was identified, as was the level of support likely needed to achieve it as applied over different body segments.

Anthropometric data was gathered, and the compromises were made for fit, support, and adjustability. All the while, in the background, consideration was given to the manufacturing process. It became apparent that the chief trade-off here was the simplicity of manufacture for adjustability of the device.

User Needs

The primary user of the wheelchair-based insert needs to be seated comfortably and securely, so that functionality and development are maximized. Existing mobility in wheelchair propulsion and transfer should be maintained. His posture should be such that his reflex patterns and general tone are normalized as far as possible.

The secondary users will want to have a piece of equipment which makes it easier to handle the child. The equipment should be simple to install, maintain, or adjust; it should be low cost; and, it should be durable. The secondary and primary user will both be concerned that the insert is aesthetically pleasing.

User Posture

The indicated posture is really quite neutral. The back is relatively erect, seven or so degrees reclined from vertical, with the shoulders in a neutral position. The seat is inclined approximately five to seven degrees with the thighs placed in a neutral or slightly abducted position. The back should be contoured, left to right, to provide a midline centering effect. The contour, however, should not be so great in the shoulder area as to provide protraction. Contour of the back should wrap partially around the lateral aspect of the trunk at the mid-thorax, to provide lateral stability. This lateral stability should extend down from there to the hip region. A lap belt will nearly certainly be needed, and a trunk belt might possibly be needed also. Another wrinkle in the shaping of the insert components was the inclusion of a 3/4-inch shelf under the thighs, to (1) provide a bucket in which the pelvis can sit; (2) to prevent the thighs from sliding forward and tilting the pelvis posteriorly; and (3) to preserve the seat/back angle. A very slight lumbar support was deemed advisable, as a slight lordosis of the lower spine often occurs in erect sitting. No provision was made for special head support. Finally, a central foam wedge between the legs, and lateral wedges beside the thighs, would encourage the neutral or slightly abducted leg position.

Photo 1. Prototype of simple wheelchair insert.

Anthropometric Data

There is a general lack of anatomical size information for disabled children. For this project, anthropometric data for non-disabled children was used to proportion the design. The anthropometric data was derived from two sources (references 1 and 2), using 50th percentile information correlating overall heights and weights at the different ages. Interpolation by formulae was necessary to yield information not available directly. (See notes to Table I).

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Table I. Children's Anthropometric Data in Sitting

		AGE			
		5	7	9	11
Sitting height:	to top of head	24.30	26.40	28.50	30.10
	to top of shoulders (1)	17.03	18.51	19.98	21.10
	to axillae (2)	12.10	13.15	14.19	14.99
	at waist	7.30	7.70	8.20	8.60
	at hips (3)	3.65	3.85	4.10	4.30
Width:	at axillae (4)	7.74	8.09	8.61	9.14
	at waist (5)	7.20	7.80	8.50	9.10
	at hips	8.40	9.20	10.20	11.20
Thickness (A P):	at axillae (4)	5.73	5.99	6.38	6.77
	at waist	5.33	5.78	6.29	6.76
Seat length:		9.90	10.80	11.80	12.80

Notes

(1) Assumed top of shoulder divided by top of head height = .5
(2) Assumed axillae height divided by top of head height = .7
(3) Assumed hips height = .5 x waist height
(4) Calculated from chest circumference, using width divided by thickness = 1.35
(5) Used bicristal width
(6) Using width divided by thickness = 1.35

It is not certain that the data in Table I is useful for the design of devices for disabled children. Two major sources of potential errors are the interpolation formulae used to fill in some of the data, and the transfer of information relevant to able-bodied children, a different baseline population. Such as it is, the anthropometric data in Table I seems to be the best available. It is presented as a point of departure--and debate--for other designers. The suitability of this information becomes part of the general evaluation of the insert designed from it.

The Design Process

The ranges of adjustment for the seat and back were decided first, using the anthropometric and wheelchair information. Next, the shape of the seat was planned using a build-up method. The seat consists of a lower and upper shelf in the back and front respectively, with a small pommel, lateral wedges, and knee divider added onto the basic shape. The lower shelf was made one inch thick, as a minimum thickness of foam that would provide comfort without unduly raising the height of the insert seat and thereby discouraging transfers. Usually the elevation between front and back parts of an antithrust seat occurs at about half of the overall length of the seat. The forepart of the seat was raised 3/4" above the back, again from clinical experience with the antithrust seat. The slope of the forepart of the seat was left at neutral, as the recline of the wheelchair would translate this to a five degree or so recline. Next, lateral wedges were added along the sides of the seat. The lateral wedges and the pommel were tapered to zero height above the front edge of the seat, to present minimal obstacles to transferring. To compensate for the lack of pommel at the distal thighs, a knee divider block was included at the front of the seat.

Detailed design of the insert back was more complicated. Basically, it was built outwards from the center line. The orientation of the center line was determined from the postural information: linear, except for the lumbar/waist portion. It was evident that there were three zones of constant crossection at the shoulders, waist, and hips, with the intermediate zones blending between those. Crossections which were sized to anatomical crossections were truncated anteriorly according to amount of support needed at the different levels.

The "corner chair" method for graphic determination of crossections is shown in Figure 1. Once identified, these constant crossections were "attached" to the centerline skeleton. The user posture criteria of the section titled "User Posture" were considered again for the transition zones. For example, the user receives (and needs!) almost no lateral support at the shoulders and axillae from the very slightly curved crossection there. But the mid-thorax receives much fuller support from its deeply-contoured cushion. Because it had been decided that full lateral support to the trunk could be diminished from mid-trunk upwards, a smooth blend was introduced between shoulder and waist crossections. However, given other design decisions, the deeper lateral supports could just as easily have been continued further up the trunk before transition began. Constant and transition zones and their linear dimensions are shown in Figure 2.

Fine tuning of the insert design was done after checking the anthropometric data against the design dimensions, and for aesthetics or simplicity of fabrication.

Manufacturing Process

It was stated earlier that one of the objectives of this design process is to develop a low-cost device. One of the major factors influencing the ultimate market price of the product will be the process by which it is manufactured. Several processes were considered: die-cutting foam; injection molding or blow molding; vacuum forming; and injection molding soft foam. Cost of producing dies for injection or blow molding rigid polymers would undoubtedly be prohibitive. Vacuum forming is a good possibility, but it does not result in a a soft foam seat without a secondary foam layer being attached. Die cutting of foam blocks appears to lack the accuracy and repeatability needed for this sort of project. It was decided that the most likely process of manufacture would be to mold a flexible polyurethane foam onto a stiffening shell. The polyurethane foam can be molded and accurately duplicate the three-dimensional curves, while the stiffening shell provides the structural rigidity required. The prototype shell was made from aluminum, brake-formed to shape, because of low overhead and ready availability. Eventually, a composite shell will likely replace this. Finally, there are already several molded polyurethane products available in the rehabilitation engineering field, and they seem to have the durability, formability, and relatively low price that this product will need for this speciality market.

CURRENT STATUS AND FUTURE PLANS

Initial design has been completed. A prototype is available for brief trials by San Francisco Bay Area disabled children who meet the criteria for age, size and diagnosis. The investigators are interested in determining how well the simple wheelchair insert meets the functional needs for support and mobility, if it is appropriately sized and proportioned, and how it is received by the primary and secondary users.

Following design refinements, prospective manufacturers will be contacted and asked to tender submissions for commercial production of the seat.

REFERENCES

G. H. Lowrey, Growth and Development of Children, 7th ed., Yearbook Medical Publishers, Inc., Chicago, 1978.

H. Dreyfuss and Associates, "Human Scale 1, 2, 3", MIT Press, Boston, 1974.

ACKNOWLEDGEMENTS

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CORRESPONDENCE

The author may be contacted at the Rehabilitation Engineering Center, Children's Hospital at Stanford, 520 Willow Road, Palo Alto, CA 94304.

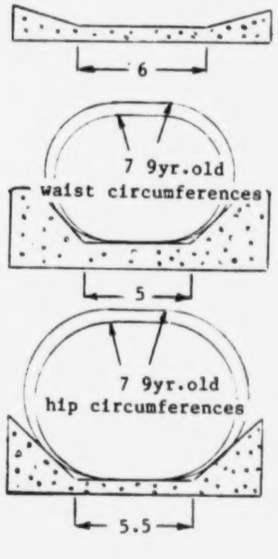


Fig. 1. Foam crossections at hip (bottom), waist (center) and axilla/shoulder (top drawing).

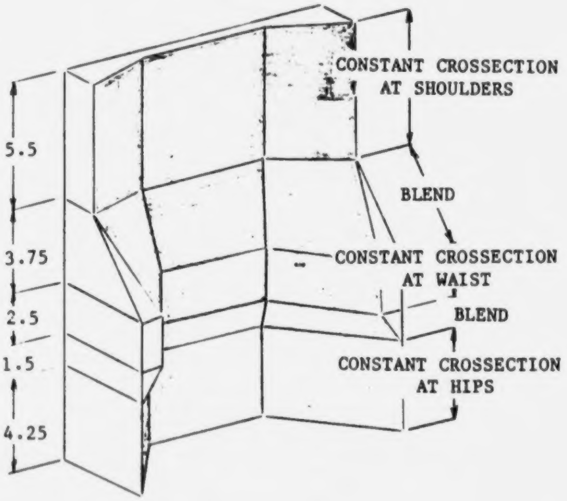


Fig. 2. Block isometric of insert back, showing zones of constant crossection. Dimensions are in inches.

THE ANTI-THRUST SEAT: A WHEELCHAIR INSERT FOR INDIVIDUALS WITH ABNORMAL REFLEX PATTERNS OR OTHER SPECIALIZED PROBLEMS

Allen R. Siekman and Kelly Flanagan
Children's Hospital at Stanford, Rehabilitation Engineering Center
Palo Alto, California

ABSTRACT

This paper describes the design and fabrication of the Anti-Thrust Seat, a seat system which is used to control the unwanted forward motion of the pelvis in clients with cerebral palsy and other diseases. Also described are the results of preliminary clinical evaluation and recommendations for further research.

INTRODUCTION

The Anti-Thrust Seat was developed in 1981 at the Rehabilitation Engineering Center, Children's Hospital at Stanford. The seat was designed to control the unwanted forward motion of the pelvis which is exhibited during extension particularly in those clients with cerebral palsy. The design has also proven to be successful in controlling forward pelvic drift in clients with muscular dystrophy, myelomeningocele, spinal cord injury and others with no active extension but who exhibit a tendency to "slip out" of the wheelchair seat.

BACKGROUND

In attempting to achieve the best seated position for a given client, the historic approach has generally been to find the postural position which most greatly reduces the unwanted abnormal tone and reflex patterns and facilitates automatic motor patterns. This has most commonly included consideration of hip flexion, orientation of head and trunk in space, head and neck position, footrest height/angle and combinations of these and other body positions (1, 2, 3). Through the application of therapy techniques and the utilization of positioning equipment, it is fairly easy to identify the best combination of body positions that will result in minimized tone and reflex patterns in the relaxed seated position. Clinical observation tells us, however, that a posture which seems optimal in the relaxed position is not necessarily easy to maintain. Excitement, a loud noise, or concentration on a task can cause reflex and tone to peak and the body to move. How many times has the therapist witnessed pelvic, trunk and head position become totally lost as the client tries to maneuver through a doorway? Many attempts have been made to minimize this extraneous motion and prevent the loss of optimal seated position. Most concentrate on maintaining the pelvis rearward in the wheelchair seat, and rightfully so, for the loss of stable pelvic position has the greatest effect on all other body position (2, 4). As the pelvis slides upward and forward during extension, the results affect pelvic angle (usually increasing posterior pelvic tilt), back angle, relative position of the body to both lateral support and headrest components, as well as support under the posterior thighs and decrease of hip flexion angle. These changes in posture not only eliminate the effects of attempts at positioning but often the resulting changes actually increase tone and reflex pattern activity.

The clients seen at this Center have severe or profound involvement. Observations during initial evaluation in the Rehabilitation Engineering Clinic indicate that, of the methods used to maintain pelvic position, the most common is the incorrect application of the abduction post or pommel. It is common practice to use the abduction pommel as a means to limit the available forward motion of the pelvis. This is sometimes even used in children with excessive abduction or who have functional considerations which are contraindicators for the use of a pommel, i.e., transfers or foot operation of wheelchair controls and/or communication aids.

Other methods to control pelvic position include increasing hip flexion with a wedge seat, the addition of groin straps or a padded bar across the illiac crest. The inability of these methods to effectively control the pelvis can be contributed to the fact that they usually apply controlling force only to the superior illiac crest or groin. Without a means to control the inferior aspect of the pelvis, the maintenance of both pelvic location and pelvic tilt is extremely difficult.

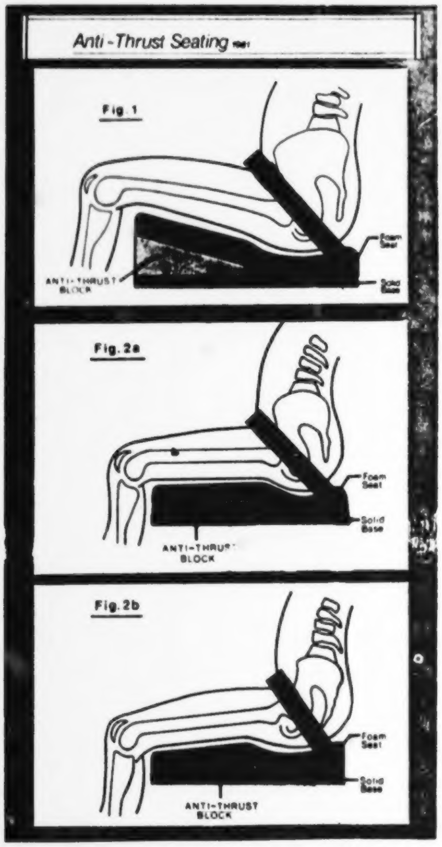
THE ANTI-THRUST SEAT

The Anti-Thrust Seat uses varying densities of foam to form a soft tissue block or "curb" which controls the inferior bony prominances of the pelvis in conjunction with a lap belt used to control the superior illiac crest. By using existing therapy techniques to establish the ideal seated posture and the Anti-Thrust Seat to maintain pelvic location, a comfortable and consistant seat position is possible.

Function

The Anti-Thrust Seat consists of four major components: 1) solid base, 2) firm density foam block, 3) soft outer foam layer, and 4) seat belt (see figure 1). The firm base, usually 1/2 inch plywood or 3/16 inch Kydex, is used to provide stability and strength for the foam components while providing a solid seat base to counter the sling effect of a standard wheelchair seat.

The firm foam block and the seat belt are the heart of the seat system. The block provides the curb which controls the ischial and pre-ischial buttocks mass and can be varied in order to provide necessary hip flexion. Placement of the curb determines its effect on anterior/posterior pelvic tilt and location of the pelvis.



Some clients have restrictions on the amount of hip flexion that can be obtained. By maintaining the curb but varying the angle of the flexion wedge the client with limited range of motion at the hip or with a fixed anterior/posterior pelvic tilt can be accommodated (see Figures 2A and 2B).

The seat belt, usually an automotive type, crosses the illiac crest at a 45 degree angle. The belt is generally tightened to contact the torso during relaxed seated posture and becomes tight during extension as the forward movement and pressure increase. The shape of the anti-thrust block combined with body position allow the buttocks to return to the relaxed position as the extension activity decreases. For those clients with an anterior pelvic tilt the seat belt can be mounted somewhat higher to help pull the superior illiac crest rearward and assist in maintaining spine/pelvis alignment.

The soft outer foam layer serves to provide a comfortable seat base while conforming to individual body contours. The distribution of pressure is accomplished with the use of two-inch Sunmate's foam.

Abduction units can be molded into the seat base to provide a gentle hip abduction contour or a removable abductor can be installed for those clients who require extra control. Under no circumstances should an abduction unit contact the groin. Whenever possible a minimum two-inch clearance is allowed between the groin an abduction unit.

Lateral hip control is accomplished with hip bolsters for those clients who need additional management of lateral hip motion.

DEVICE EVALUATION

The importance of clinical evaluation or field testing within the process of prototype development has been described for communication aids (1) and seating and mobility technology (7, 8). Platt and Hobson (7) described an evaluation methodology including an assessment of user needs, prototype design, fabrication and evaluation, outside clinical evaluation and dissemination of the clinical evaluation results to potential manufacturers. That process forms the basis for the clinical evaluation methodology utilized at this Center. Accordingly, the Anti-Thrust Seat is currently undergoing clinical evaluation to determine its effectiveness in maintaining upright posture, inhibiting involuntary movement as a result of abnormal reflex patterns and thereby decreasing the frequent repositioning required to maintain an optimal seating position.

Selection of Subjects and Methodology

Fifty patients who had received an Anti-Thrust Seat between 1980 and 1982 as part of their treatment at this Center were selected to be subjects for the study. Subjects ranged in age from five to 32 years with a median age of 14. A questionaire on the Anti-Thrust Seat was sent to each subject/family/caregiver, along with a letter describing the purpose of the study. The questionaire asked the respondents to estimate: 1) the number of times per day the client needed repositioning, 2) the degree of comfort provided by the Anti-Thrust Seat, 3) the sitting duration in hours per day, and 4) whether or not the client's sitting posture had improved since receiving the Anti-Thrust Seat. Respondents were also asked to rate the safety, durability, workmanship/design, appearance, and convenience of the seating system.

Results

Only preliminary results are available. At this writing, 40% of the subjects have returned completed evaluation questionaires. Final results are anticipated by May 31, 1983. Of those subjects responding, diagnoses included cerebral palsy with spastic quadriplegic involvement, cerebral palsied with ataxic involvement, and other diagnoses including muscular dystrophy, arthritis, spinal muscular atrophy, and myelomenigocele. Of the subjects who responded, six were between the ages of five and 10, and the remainder ranged in age from 11 to 32. The preliminary clinical evaluation data are reported in Table 1.

TABLE 1. PRELIMINARY CLINICAL EVALUATION RESULTS FOR ANTI-THRUST SEAT

PERCENTAGE OF RESPONSES IN EACH CATEGORY

QUESTIONS

OF REPOSTIONS/DAY

NEVER	1/DAY	2-3/DAY	4-5/DAY	1/HR
59%	4%	14%	14%	9%

# HOURS SITTING/DAY

8	5-8	2-4	1-2	1/2-1
29%	24%	29%	14%	4%

COMFORT

HIGH 5	4	3	2	LOW 1
29%	24%	29%	14%	4%

POSTURE IMPROVEMENT

YES	NO	NO RESPONSE
57%	38%	5%

These preliminary data are encouraging. 59% of subjects report that repositioning is never necessary, that 53% are able to sit in the Anti-Thrust Seat for approximately five to eight hours or more per day with an optimal amount of comfort (four or five on scale of one to five). 57% of the subjects report an improvement in posture particularly in the cerebral palsied segment of the subject population. Written-in reponses indicate that the posture question was misunderstood by some subjects. Responses suggest that subjects were under the impression that we were asking if any physical changes in posture (e.g. correction of physical or structural deformities had occurred as a result of the Anti-Thrust Seat). Patients with degenerative conditions would, of course, be less likely to experience this sort of change which would account for the negative trend in the data for the non-cerebral palsied portion of the subject population. The overall findings are positive.

CONCLUSIONS/RECOMMENDATIONS FOR RESEARCH

The evaluation of the Anti-Thrust Seat thus far suggests some design modifications. These include decreasing the thickness of the front edge of the wedge cushion with possible changes in the plastics used for the solid base. Preliminary clinical trial results suggest that the Anti-Thrust Seat design is effective in the treatment of seating problems frequently occurring as a result of cerebral palsy or other muscular diseases affecting gross motor patterns and therefore postural control. The initial results suggest possible directions for future research: 1) further clinical evaluation of the Anti-Thrust Seat design on a larger subject population, 2) study of the effect of the Anti-Thrust Seat in reducing muscle tone, and 3) longitudinal study on the long-term effectiveness of the Anti-Thrust Seat in decreasing need for surgical intervention due to control of contractures and other deformities.

SEATING BIBLIOGRAPHY

1) Bobath, B., Abnormal Postural Reflex Activity Caused By Brain Lesions, William Heinemann Medical Books Limited, 1971.

2) Trefler, E., OTR, Toomes, R.E., M.D., and Hobson, D.A., "Seating for Cerebral Palsied Children", University of Tennessee Center for the Health Sciences, Rehabilitation Engineering Center, 1248 LaPaloma St., Memphis, TN 38114, 1980.

3) Bleck, E.E., Nagel, D., Physically Handicapped Children, A Medical Atlas for Teachers, N.Y., London, Grune and Stratton, 1982.

4) Bergen, A.F. and Colangeio, C., Positioning the Client with Central Nervous System Defects, Valhalla Rehabilitation Pub. Ltd., Valhalla, N.Y., 1982.

5) Sunmate, Dynamic Systems, Inc., Route 2, Box 182B, Leicester, N.C. 28748.

6) Coleman, C.L., Ph.D., A.M. Cook, Ph.D., and L. Meyers, Ph.D., Final Report Submitted to Department of Education for Field Initiated Research Project Enhancing the Education Potential of Non-Oral Chldren Through the Matching Communication Device Capabilities to Children's Needs, Grant No. G007902261, CFDA #13, 443c, 1982.

7) Platt, P.H. and D. A. Hobson, "A Proposed Methodology for Rehabilitation Engineering Decision-Making", Proceedings of the International Conference on Rehabilitation Engineering, Toronto, 1980.

8) Levy, R., K. Waksvik, and P. Nelson, "A Clinical Evaluation Procedure for Communication Equipment for the Speech Impaired - A Case Study, with Recommendations, on the Blissterm and M.C.C.S.", Proceedings of the Fourth Annual Rehabilitation Engineering Conference, Washington, D.C., 1981.

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7.5 WEBBED ELASTIC FOR POSTURAL SEATING IN CASES OF SEVERE DEFORMITY

D.A. O'Rourke
Rehabilitation Engineering Department, Ontario Crippled Children's Centre

ABSTRACT

In the past year a webbed elastic back support system has been successfully employed for severely deformed patients with cerebral palsy. This system accomodates the deformities while giving postural support and comfort. This paper outlines the methods used and provides two illustrative examples.

INTRODUCTION

In institutions with a lack of funds, postural seating has generally had a low priority. As funds have become available and knowledge regarding the everyday living needs of a disabled persons has increased, seating has become recognized as a very basic prerequisite for habilitation and rehabilitation.

Regretfully, many of those confined to institutions have lingered in beds too long and have acquired lopsided backs, or rib humps. Deformities become fixed so lack of hip flexion and tight hamstrings may also present problems.

In seating a client with a rib hump (See Figure 1) pivoting on a flat back support causes the body to rotate. Frequently the rib cage rests on the pelvis.

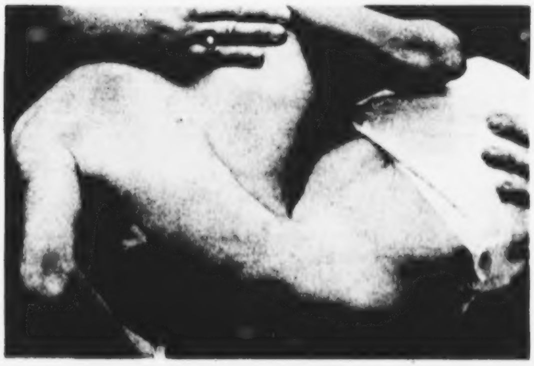

Figure 1: Rib Hump

The cerebral palsied client with a kyphotic back, often caused or aggravated by poor seating, lack of motivation or stimulation, has a tendency to push out of the seat upon contact with the back.

By allowing space for either the "rib hump" or the kyphosis the client can sink into the back allow the pelvis to be better positioned with comfort.

There are several ways to achieve space for the deformities of the back including:

- Sculpting foam and filling in spaces.
- Creating a poured foam back.
- Having a plastic mould lined with foam.
- Using styrofoam beads mixed with resin and shaped around the back.

All these would certainly provide support but tolerable durations in the chair would be drastically cut as in our experience rigidity does not lend itself to comfort.

If the client is placed improperly in the seating device by uninformed personnel, pressure areas could develop and lead to even greater problems of pain and suffering which can lead to costs in the order of thousands of dollars in hospital care.

Growth, particularly with children, is another factor that negates many of the form fitting methods.

THE SOLUTION

Having weighed all of these issues, a solution which emerged was to utilize a webbed elastic back (see Figure 2). A shoulder-height, rectangular, plywood box is constructed several inches deep as dictated by the prominence of the rib hump. Corners are braced and T-nuts inserted for attachments i.e. laterals and a head support bracket. The height of laterals may be made adjustable by inserting another level of T-nuts. Laterals are padded appropriately to fulfill support needs. Webbed elastic has also been used as a "sling" lateral.

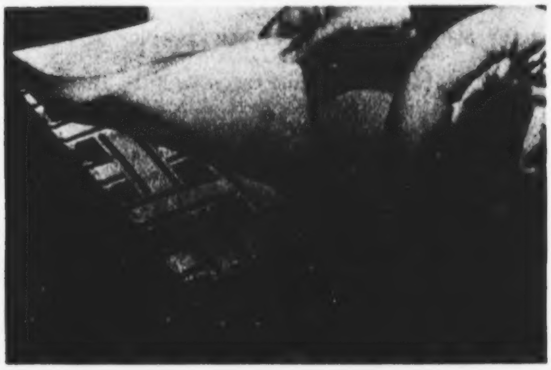

Figure 2: Construction of Webbed Elastic Back

The box is usually recessed in a wheelchair between the upright push bars to maintain the centre of gravity over the rear wheels.

Soft-edged "truss" elastic*, one and three quarters inches in width is then interwoven horizontally and vertically over the box, leaving surplus webbing at the top and one side to allow for adjustment. One inch of polyfoam is placed over this.

Fitting the interface can commence once the box has been hinged to the seat. The hinges are located under the front of the lower panel and to the underside of the seat.

The position of the rib hump or kyphis is noted and the webbing is carefully released in this area. With the pelvis well positioned and the trunk aligned and having accommodated the deformities, the elastic web members can be reaffixed. The polyfoam is then placed into position on the depressed webbing.

Figure 3 reflects the completed system at the fitting stage prior to the finalization of the usual naugahyde and terry-cloth (seat and back) covering. A Mooney base is provided for mobility.

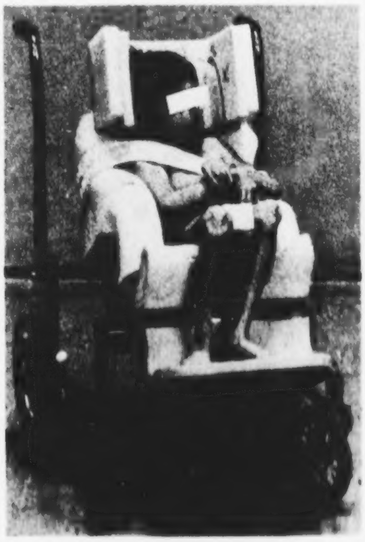

Figure 3: Support system to be covered

ON FIXED HIP DEFORMITIES

The problems of fixed deformities of the hips, and little or no hip flexion have also been addressed. Normally individuals with this problem would be recognized as non-sitters. Some measure of respite from their beds has been possible with the development reflected here (See Figure 4).

Using a wooden box, measured to include the body from the head to the thighs, interwoven webbed elastic is installed on a frame usually about three inches up from the bottom. This webbing may also be released to accept prominences of the body into the box ensuring that bottoming out does not become an irritant and positioning is easier. Selective suspension is a useful added feature.

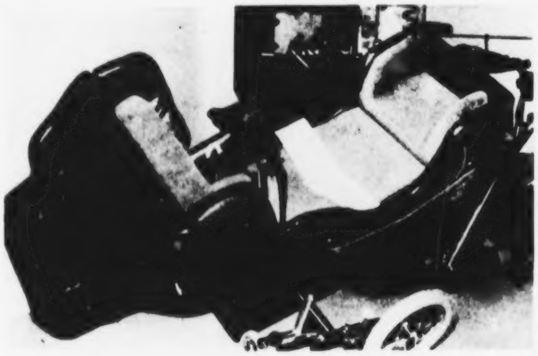

Figure 4: Support system for individuals with fixed hip deformities.

A hinged seat with an angled leg-foot support is added. The hinges are situated inside the box at the lower end. In the fitting, appropriate degrees of flexion, if any, can be established.

Depending on the high pressure areas to be relieved, various foams are used to pad out the box. The head-rest is included in the box and here again foams are utilized according to density and need. Ethafoam makes a good foundation from which to build. High density polyfoam wears well in heavy duty areas such as on seats for young adults with strong extensor thrusts. Ordinary upholsterer's polyfoam is satisfactory for average wear.

Super-soft polyfoam may be used for the extremely sensitive patient.

Temper-foam spreads pressures and helps control potential skin breakdown. It is colour coded. T-41 (blue) is used in standard care cushions, T-38 (pink) is used for light, fragile patients.

The wooden box is water-proofed by brushing on a plastic coating and a few drainage holes are drilled. Double four-notch adjustment bars are placed on the bottom of the box at head level with a polycarbonate lock on the notches used. The "Mooney" base accepts this device with a locking bracket on the front end of the box base.

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* The Longdon Foundation, 781 King Street W., Toronto, Ontario, M5V 1N4, (416) 363-2367.

Sheet latex can be used to cover the lower half of the back for the incontinent patient. The final cover is a two-way stretch Terrycloth - 80% cotton, 20% synthetic - velcroed to the naugahyde covered box to enable ease of laundering.

Mooney bases are sturdy and chromed, have two twelve-inch wheels, two eight-inch casters and two bars for stabilization at seat level and one at axle level. The push handles will fold down, making it easier for transportation. Such a base is shown also in Figure 3. This base will also accept an insert using the four-notch adjustable bar on the back and the locking bracket under the front of the seat. The plywood laterals hold the back by 90° metal bars to the underside of the seat. The angle of recline between back and seat is fixed, but the complete insert can be reclined.

Trays that we provide are usually made of arborite covered plywood with a moulded bumper and rounded corners. These may be mounted on a wheelchair or the fixed angle insert. Their use includes promotion of communication, play, feeding, encouragement of hand function, and support for positioning. A folding tray may be attached to the side of the "fixed deformities" model as an area for the care-giver to feed from or hold supplies while attending the client.

VALUE OF SYSTEMS

In 1982, approximately twenty-five percent of some six hundred dispensed seating systems have included the webbed elastic construction. It is generally acknowledged that this arrangement is a significant contributing factor to appropriate seating for severely involved individuals including those with cerebral palsy.

The few extra hours involved in construction and adjustment are greatly outweighed by the expressions of, and advantages to clients who have not sat before. They are now up with their peers, easily transportable, and easier to feed. The provision of such systems often marks the beginning of the realization of their potential.

Responses from the several institutions whose patients have been serviced have been very positive. The care of their clients has been greatly facilitated. Parents are delighted to see their child comfortable. In general, tremendous gains have been found in regard to respiratory function.

ACKNOWLEDGEMENTS

The implementation of the system described is attended to by a vigorous team in the seating programme. Their contributions are gratefully acknowledged.

Ontario Crippled Children's Centre
350 Rumsey Road
Toronto, Ontario
M4G 1R8

BEAD SEAT INSERT SEATING SYSTEM

Douglas A. Hobson, Michael J. Heinrich, and Sam F. Hanks

University of Tennessee Center for the Health Sciences
Rehabilitation Engineering Program
Memphis, Tennessee

OBJECTIVE

The objective of this project has been to investigate the potential of the vacuum consolidation technique as a means of evaluating for and providing a definitive seating insert. The insert would then be interfaced with a wheeled base - the standard wheelchair being the most obvious.

BACKGROUND

The technique of vacuum consolidation of small light weight beads (polystyrene) within an airtight bag has been used clinically for approximately ten years to take impressions or stablizing of body segments. Letts and Hobson published an article which indicated the use of the technique for temporary fracture bracing (1). The Institute for Medical Research in Holland first published results of an approach which resulted in the permanent fixation of the beads through introducing an epoxy into the beads prior to the final shaping and evacuation of the bag (2). After a period of six to eight hours the epoxy will set and bind the beads together permanently and thereby retain the desired shape.

The DESEMO project first demonstrated the permanent fixation technique in the United States. The DESEMO approach utilizes a weather balloon, small polystyrene beads, and a two component epoxy resin as the binding agent.

Viewed from a comprehensive seating service standpoint the Dutch and DESEMO approaches do not meet several additional requirements. These requirements are related to: need for exceptional durability of definitive seats, adequate restraint safety in wheelchairs, aesthetics, resiliency of surface textures, the need to reduce time and associated labor costs to a minimum, and one day availability for out-of-town clients.

The Bead Seat Insert (BSI) investigation at UT-REC should be regarded as a further refinement of the above mentioned developments, with particular emphasis being placed on the following clinical and financial objectives.

* A series of adjustable seat, back, and headrest components that can be interfaced into at least three sizes of standard wheelchairs.
* An increased resiliency of the bead/resin matrix substructure so that it approaches firm foam.
* An ability to have a Bead Seat Simulator (BSS) for use in evaluating patients for a BSI or other types of aids such as powered mobility, communication, etc.
* An ability to readily hand contour the beads/resin matrix to accommodate the most severe orthopedic deformities.
* An ability to evaluate, fabricate, fit, finish, and interface a complete BSI in less than four hours.
* An overall system design that permits application with only minimum of on site technical resources.
* An overall system design that permits commercial production and marketing at retail prices that are within accepted cost ranges for total body support seating inserts.

CONCEPT DEVELOPMENT

The BSI vacuum consolidation seating approach utilizes the concept of having a moldable matrix within a flexible envelope that can be readily molded directly around an individual to provide custom body support (seat, back and headrest). Molded supports are solidified initially through consolidation using a low vacuum, and then permanently by the curing of the adhesive which permanently binds the beads/resin matrix. This is followed by applying an acceptable outer covering material and finally, interfacing the insert into a wheeled base. The UT-REC approach has utilized this basic concept and evolved the Bead Seat Simulator and the Bead Seat Insert as complimentary components.

Bead Seat Simulator (BSS)

Clinical experience over the past ten years has demonstrated the desirability of being able to simulate an individual's definitive seating configuration during the evaluation process. This capability provides two advantages. The first is that for very little cost an individual can be evaluated as to the appropriateness of the seating system for their particular needs. This gives the clinician an opportunity to actually observe the functioning of the seating support prior to recommending its purchase. Secondly, it provides a rapid means for obtaining seating support that simulates the support that will be derived from the definitive seat. This latter capability can be a communication aid. This is particularly important when expedient decisions have to be made about prescribing expensive devices, especially when upper limb control is only marginal. The Bead Seat approach readily permits the development and use of a simulator as a complimentary component to the BSI system.

Basically, the Bead Seat Simulator (BSS) utilizes the identical approach and components that are used in the definitive seat (BSI). The only difference is that the viscous liquid that is added to the beads to form the viscous matrix material within the flexible envelope does not become solidified in the simulator application. This means that the simulator components can be reshaped and vacuum solidified to support and evaluate many different individuals. Of course, a vacuum must be maintained on the mold in order to maintain the consolidation. The vacuum can be maintained with a one way valve, a small battery powered vacuum pump, an asperator, or a larger 110 volt vacuum pump. The viscous liquid should be non-toxic (we currently use vegetable oil), and should have a low vapor pressure so that it will not readily evaporate.

The BSS components are designed to fit three common sizes of standard wheelchairs beginning with the standard adult size. The simulator seat and back molds can be fastened on top of the wheelchair upholstery with velcro straps, or upon removal of the upholstery fastened in place with adjustable hardware. The back mold has a receptacle to receive a variety of head rests, which are often necessary to assist in head control. The flexible surface of the molds are latex rubber sheeting which permits easy shaping of the inner matrix material while still providing durability.

After an evaluation in the BSS, one would proceed to a definitive seating system - the Bead Seat Insert being one option.

Bead Seat Insert (BSI)

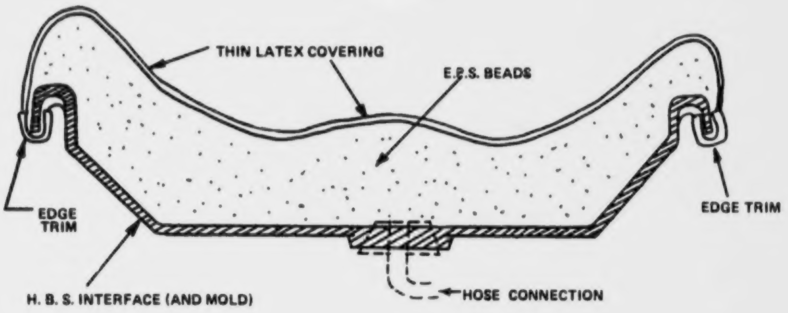
Since the concept is still in the investigation stage, the scope of present design accommodates only three sizes of standard wheelchairs (Junior 13, narrow adult, adult). Fabrication of a definitive BSI proceeds through the following steps: a) preparation of matrix material, b) attachment of molds to wheelchair, c) contouring of matrix material, d) finishing procedures, and e) final interfacing.

a.) Preparation of Matrix Material - The approach being investigated currently consists of small size polysturene beads (approximately 1.5 mm diameter) into which is kneaded a two component polyurethane adhesive. The bead/urethane matrix has a working time of approximately thirty minutes and is cured ready for final covering within approximately two to three hours. Application of moderate heat (less than 60° C) can further reduce the curing time.

The actual molds are comprised of a plastic vacuum formed tray over which is stretched latex sheeting. The latex is sealed airtight around the edges using a flexible clip-on edge trim. A two inch diameter hole through the under surface of the tray permits the pouring in of the beads and the polyurethane adhesive. The plug that seals the filler hole also contains the tube for attachment of the vacuum line (See Figure below).

b.) Mold Attachments - As previously mentioned the molds can be attached to wheelchairs both temporarily (as in the BSS application), or permanently. For a definitive seat it is best to remove the standard wheelchair upholstery since it usually is a hinderance to obtaining the desirable positioning within the wheelchair. The plastic tray portion of the seat mold is designed to fit on top of the wheelchair seat rails. The attachment is made secure by adding a short piece of wheelchair clamping bracket extrusion to the seat rails. This attachment minimizes the A/P and M/L seat movement. Adjustable hardware permits A/P, height, and recline adjustments of the back mold to accommodate for thigh length, back height and A/P trunk alignment, respectively. Quick release fasteners permit the easy removal of the seating

SEAT SECTION



components to permit the folding of the wheelchair.

c.) Contouring the Supporting Matrix - Actual contouring of the supporting matrix is done in two or more stages. First, the seat mold is prepared as per above, while the back mold is left dry (beads only in the mold). In this way the back mold can be used to provide trunk support while the seat contouring is being carried out. Once the seat contouring is complete, and the vacuum applied, the back mold is prepared (adhesive kneaded into the beads) and then contoured around the individual while they are still sitting in the already completed seat mold. This process assures good matching between the seat and back components. If necessary, the third step would be to fabricate a custom head support following the same steps.

Once the matrix material has been prepared within the latex sheeting, it has a consistency of molding clay. With the aid of a light vacuum (2-3 in. HG) the material will hold any position into which it is molded. Generally, it is best to do some preshaping under light vacuum prior to involving the disabled person. Subsequent manipulation of the matrix can readily accommodate leg length discrepancy, pelvic assymmetry, hip adduction/abduction, leg/trunk angle, pressure relief, lateral trunk support, lumbar support, and shoulder protraction. After mixing of the matrix, the working time is about twenty minutes, during which time multiple configurations may be attempted in order to finally obtain the type and degree of support required by the individual.

Once the final configuration has been obtained, application of a 5-6 in. HG vacuum will rigidly consolidate the matrix. The vacuum may be removed after approximately two hours and the finishing procedures initiated.

d.) Finishing Procedures - Since the finishing is a separate and final step, the potential exists for introducing options in terms of colors, surface textures, additional cushioning, or subsequent modifications if presure points or slight misfits become evident.

As a result of using a flexible polyurethane polymer as the binding agent within the matrix the cured components have a resiliency approximating firm closed cell polyethylene foam (Ethafoam). Further options in the choice of matrix resiliency are also possible through the use of more or less flexible bonding polymers. Also, flexible seating components usually have improved the durability over that derived from using rigid components. Rigid components are obtained when rigid epoxies are used as the bonding agent. The use of flexible polymers is believed to be unique to the UTREC approach. A number of finishing procedures are available depending upon the resources available to the applications team.

e.) Final Interfacing - Since the fabrication of the seat and back components took place within the disabled persons wheelchair, the interfacing procedures are already completed except for possible minor adjustments to back angle, thigh length, head support, positioning, etc. That is, the plastic trays which serve as the basis of the seat and back molds also serve as the interfacing components. This attachment hardware used to attach the seat and back molds is already in place on the wheelchair, so only minimal additional time should be required for this aspect of the final interfacing step.

As with all seating systems, appropriate lap and chest restraints, foot rests and lap trays would be added to the basic BSI system, as required by the individual. Assuming these accessories are readily available as pre-fabricated parts, preliminary results indicate that completion of all the above steps is possible within four hours.

CONCLUSIONS AND FUTURE PLANS

Clinical experience with six fittings suggest good potential for the BSI approach. Six additional trial fittings are planned for completion by mid 1983. Successful design refinements resulting from these trials should render the BSI system ready for commercial availability by year end.

REFERENCES

1. Letts, R. & Hobson, D., "The Vacuum Splint: An Aid In Emergency Splinting of Fractures, Can. Med. Jour. Vol. 109, Oct., 1973.

2. Wijkmans, D.W., "Body Casts for Adapted Seats Made by Vacuum Fixation Tech.: Intro. in Practice, Prog. Rep. No. 5 - Inst. of Med. Phys., UTRECHT, Netherlands, Dec. 1976.

Douglas A. Hobson
University of Tennessee - REC
682 Court Avenue
Memphis, Tennessee 38163

7.7

SIDE-BY-SIDE TRIALS: AN EVALUATION METHODOLOGY FOR COMPARATIVE TESTING OF MODULAR WHEELCHAIR INSERT SYSTEMS

Susan P. Schaezlein, OTR and Richard N. Holte, MSc.
Children's Hospital at Stanford, Rehabilitation Engineering Center
Palo Alto, California

ABSTRACT

This paper discusses the project design, evaluation methodology and preliminary impressions of the Side-by-Side Trials of modular wheelchair insert systems. At this writing, four out of 10 subjects have participated in the study. Project completion is anticipated by May 1983. Final results will be presented at the RESNA Conference.

INTRODUCTION

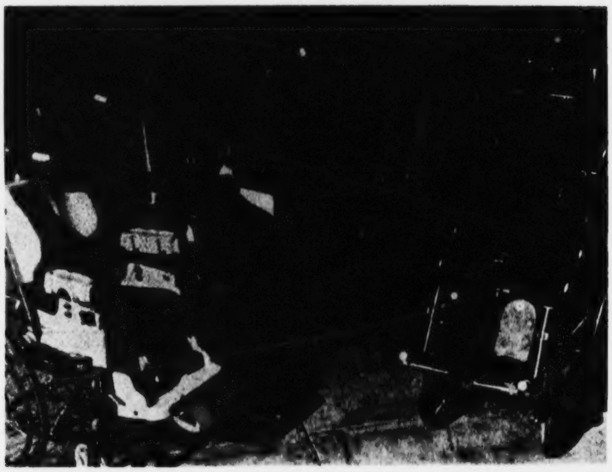
Side-by-Side Trial methodology was developed at the Rehabilitation Engineering Center, Children's Hospital at Stanford as a process to evaluate functional and technical features of four commercially available modular wheelchair seating systems and to determine: 1) the specific features and components of a modular seating system which improve or decrease user function; 2) technical modifications which could be made on existing seating systems to better meet functional needs of users; and 3) necessity for the development of a new modular seating system. Using a side-by-side evaluation methodology, child subjects with the diagnosis of cerebral palsy are fitted in each of the four seating systems and perform specific functional activities. Each seating system is rated on: ability to provide postural control; affects on certain functional activities; manageability by a parent; and technical characteristics.

BACKGROUND

Over the past five years a number of wheelchair based modular seating systems have been developed and marketed to provide postural control for individuals with cerebral palsy. Theories have been advanced to explain how seating systems should be configured for an individual. The characteristics and components of these seating systems have been designed to provide an orientation in space, provide support or exert forces on the body to improve anatomical alignment and stabilization, and influence muscle tone to improve seating posture. A method of comparing the relative merits between these systems has not yet been formalized.

Case studies and device studies have been conducted to evaluate seating systems. Most are evaluations of single systems versus comparative studies of several different systems.

With no methodology format available to meet the needs of our project, a unique methodology was developed as a process to evaluate functional and technical features of commercially available systems in side by side fashion.



Seating Systems evaluated in the Side-By-Side Trials: MPI, Winnipeg, Britax, Mulholland

PROJECT DESIGN AND METHODOLOGY

Equipment Selection

A market search utilizing ABLEDATA files and equipment catalogues was done to identify existing commercially available modular wheelchair insert systems. A survey of local professionals with expertise in seating was conducted to identify those seating systems which were of the most interest and had the most promise for inclusion in the study. Final selection of four modular seating systems was based on the system's representation of a "type" of wheelchair insert, its range of optional components, versatility in adjustment, and integrity of the manufacturer. The Mulholland Adaptive Positioning System for Standard Wheelchairs (2), MPI System (3), Winnipeg Modular System (4) and Britax Seat (5) were chosen and purchased in conjunction with an appropriate wheelchair as its base.

Subject Description

Subject criteria was established for a specific population of severely involved children with quadriplegic cerebral palsy to reduce variability among subject. Size of the child was specified to insure general fit into the seating systems purchased for the study. Other criteria was specified to obtain subjects who would respond to postural manipulations and requested functional activities. Necessary characteristics of subjects included:

Diagnosis. Severe cerebral palsy, quadriplegia; spastic, athetoid or mixed tone patterns.

Size Range. Hip width: 9" - 11"; leg length: 12" - 15"

Neuromuscular Status. Presence of reflex activity and abnormal tone that interferes with wheelchair seating.

Orthopedic Status. No more than 20 degrees of structural scoliosis; minimal pelvic obliquity (correctable to neutral); absence of hip dislocation.

Sitting Status. Difficulty maintaining a desirable posture in an unmodified wheelchair; candidate for use of positioning components for control of pelvis, hips and trunk. May also require head and foot positioning.

Cognitive Function. Ability to comprehend directions such as "wheel yourself through the doorway", "try to get out of the wheelchair by yourself", etc.

Upper Extremity Function. Minimum requirements: gross grasp and release; interest in manual manipulation.

Age Range. 7 to 11 years.

Establishment of Subject and Evaluator Pools

With administrative approval of State California Children Services' (CCS) therapists and children from local Medical Therapy Units participated as subjects and evaluators in the study. A parent of a selected subject was also included as an evaluator.

Development of Evaluation Forms

Three evaluation forms were developed:

Fitting evaluation. The fitting evaluation was designed to rate seating system components on adjustability and ability to provide specific postural control. A rating scale of 1 to 5 was used (1 = very poor, 5 = very good).

Activity analysis evaluation. The Activity Analysis Evaluation was designed to rate the influence of the seating system on the subject's performance of functional activities. Activities included transfer, mobility, eating, desk activities and throwing/catching a ball. A rating scale of improved/no change/decreased was used.

Parent assessment. This assessment was designed for the subject's parent to rate the following features of a system: appearance, cleanability, assembly/disassembly, transportaity by car and usefulness in the home setting. A rating scale of 1 - 5 was used.

Technical assessment. Technical assessment was done informally by the project mechanical engineer and problems were noted as they came up. Repairs and modifications were made as needed.

EVALUATION METHODOLOGY

Subjects came to the Rehabilitation Engineering Center with their parent(s) and CCS therapist. Subjects were fitted in each of the four modular seating systems and performed specific functional tasks. The project occupational therapist, CCS therapist and parent rated the subjects, using evaluation forms designed for the study.

A fitting procedure was done first. Adjustments were made on a seating system and its components until optimal posture of the subject was achieved. Determination of optimal posture was made by both therapist evaluators. A seating technician was present to make necessary adjustments and modifications. Scores were recorded separately by the project occupational therapist and CCS therapist on the fitting evaluation form.

After the fitting was completed, an activity analysis was done while the subject was seated in the modular seating system. The activities were directed by the project occupational therapist in the following order: 1) throw/catch a ball; 2) mobility activity involving self propelling the wheelchair; 3) desk activities of coloring/drawing and toy assembly; 4) eating and drinking; 5) transfer out of and into the wheelchair seating system. The subject's parent and therapist determined the scoring, based on their knowledge of the child's performance abilities. Observations were recorded regarding the system's ability to control posture during activity. Enhancement or interference with function from seating system components were also noted.

The parent rated each system, using the parent assessment evaluation after examining the system with the child seated in it and by itself. Scores were based on the subjective views of the parent. Comments were recorded regarding each of the features.

The evaluation procedure was repeated for each of the modular seating systems. Two seating systems were evaluated during a morning session and two systems were evaluated during an afternoon session, following a lunch break. The subject spent between 30 to 45 minutes in each of the seating systems. Rest periods for the subject were taken whenever necessary.

DISCUSSION OF PRELIMINARY FINDINGS

At this publication, four out of 10 subjects have participated in the Side-by-Side Trials of modular wheelchair insert systems. Preliminary impressions of the four systems under evaluation are:

Britax Seat

The Britax is not felt to be appropriate as a definitive wheelchair insert system for the subject population in this study. Its size and shape were limiting factors in user function. It is best used as a car seat, as recommended by the manufacturer.

Positive features. The user feels secure in the seat. Mid-line bimanual hand use is facilitated by blocking excessive horizontal abduction at the shoulders. The harness system secures the pelvis. It can be adjusted without tools.

Negative features. Elbows can get caught between body and side structure of seat during activities. The harness system cuts into the user's shoulders. Wheelchair wheels cannot be reached because of the side structure. Shell structure limits the user's visual field.

Mulholland Adaptive Positioning System for Standard Wheelchairs

This is a appropriate insert system for the subject population. It provided better postural control for the more severely involved subjects.

Positive features. Provides good postural control and has a wide range of adjustability to meet user needs. Functional activities were improved with the exception of transfers.

Negative features. Appearance is contraption-like. Technical knowledge and a variety of tools are needed to assemble and adjust the system. Shoulder pads, lateral trunk supports and pelvic stabilizerare not user operable, preventing independence in transfers. Attaching the assembled seat base and seat back onto the wheelchair frame is relatively difficult.

Winnipeg Modular System

The system is appropriate for this subject population. It can be easily managed by parents and was favored for its appearance.

Positive features. Overall appearance is good. It is easily removed and inserted to wheelchair base; functional activities were improved. It provided good control for moderately involved subjects.

Negative features. Tools, machinery and technical knowledge are needed to assemble the system. It is not available on the commercial market in the United States.

MPI

This is appropriate seating for this subject group. It provided postural control for the less involved subjects, but not quite enough for more severely involved subjects.

Positive features. Seat depth, back height and seat angle adjustments are versatile. It has the appearance of a child's chair.

Negative features. Material is perceived as breakable and uncomfortable. Footrest and headrest hardware needed to be modified before they would fit into their brackets. Independent or assisted standing transfers were limited by the footrest component. Handles for the angle adjustment clamps broke off.

CONCLUSIONS

The modular seating system which effectively positioned a child had a positive effect on performance of most functional activities. Components of the system, however, can restrict some functions. Fixed footrests and abduction units were not user operable decreased performance in transfers. The relationship between modular seating system and its wheelchair based influenced effectiveness of the system. The relationship of the footrests to the seating system affected overall posture. The relationship of the seating system to location of the wheels influenced mobility. Appearance was important to therapists and parents and was generally the first feature considered when assessing a system. Although manageability of a system by a parent was considered important, the parent tended to place the child's needs first. They indicated a willingness to put up with a cumbersome system if it helped improve posture and function of their child.

The Side-by-Side Trials have been a useful method of gathering comparative information about modular seating systems. The trends of the study have been interesting, but no conclusions can be drawn until completion of the project. The methodology developed for this project could be useful in the comparative evaluation of other seating systems and other assistive devices.

ACKNOWLEDGEMENTS

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REFERENCES

1) "Evaluation of the Modular Plastic Insert (MPI) Seating System: A Preliminary Report"; University of Tennessee Rehabilitation Engineering Program, 1979. Prepared by Paula H. Platt, MEd.
2) L. Mulholland Corporation, 215 North 12th Street, P. O. Box 391, Santa Paula, CA 93060.
3) MED, Inc., 1701 South First Avenue, Maywood, IL, 60153.
4) Rehabilitation Centre for Children, 633 Wellington Crescent, Winnipeg, Manitoba, R3M 0A8, Canada.
5) Childsafe, Box 633, Pacific Palisades, CA 90272.

THE INFLUENCE OF INFLATION PRESSURE ON THE EFFECTIVENESS OF AIR FILLED WHEELCHAIR CUSHIONS

Rebecca Williams, M.Eng., Baylor College of Medicine
Thomas Krouskop, Ph.D., Baylor College of Medicine
Philip Noble, M.S., Baylor College of Medicine
James Brown, Rehab. Engr. Tech., Baylor College of Medicine

INTRODUCTION

Air filled cushioning devices have a long history as camping equipment and as wheelchair seats. It has only been in recent years that new concepts have been incorporated in the design of air filled wheelchair cushions to make them less prone to "bottoming out", more effective in redistributing weight, provide better trunk stability, and allow air circulation for moisture control. The ROHO and Gaymar Soft-Care systems represent innovative solutions to these traditional problems and are becoming very popular alternatives to polymeric foam wheelchair cushions. With recent rulings in California and Boston that restrict the use of polymeric foams for therapeutic bed surfaces and wheelchair cushions, there is an increasing consciousness on the part of both the consumers and providers that air filled cushions exist and can be used effectively to provide protection from pressure induced tissue trauma. Unfortunately, even this new generation of air filled cushions present several classes of problems which restrict the use of these devices. A common experience in our program at The Institute for Rehabilitation and Research and other hospitals in the Texas Medical Center relates to people's habits that cause puntures in the flotation devices. Pet cats, smoking, sewing and working in areas where hot objects may contact the wheelchair cushion are conditions that may mean that an air filled device is inappropriate for a particular client(1). The second class of factors that affect the utility of a fluid filled cushion focuses on how conscientious the user is in maintaining the "correct" amount of fluid in the bladder. It is this set of problems, how much air is needed to provide suspension and how sensitive the cushion is to the amount of air in it, that this study addresses. The issues explored in this paper are:

1. Is there a universal inflation pressure for each cushion that will maximize the protection provided by the air cushion for all potential users?

2. How sensitive is the performance of air filled cushions to over and under inflation?

METHODOLOGY

Fourteen subjects were evaluated and classified according to sex age and body build; (see Table 1) a PEP system was utilized to monitor interface pressure; a pressure gauge was connected to a compressor which controlled the internal pressure of the air cushion being evaluated.

Table 1

	Thin	Average	Overweight	Total
Male	3	4	2	9
Female	2	3	0	5
Total	5	7	2	14

The cushions under evaluationwere placed on a flat hard surface on a standard chair. With the PEP pad placed on the cushion, the individuals were asked to sit with their backs straight and supported while necessary adjustments were made to obtain hip and knee angles of 90°. The sensor pad was then inflated to open the switches and slowly deflated until the first switch closure occurred, the corresponding maximum pressure being recorded. Maximum pressures were consistently located under either the right or left ischium. Readings were taken three times and averaged for each of the three cushions being evaluated.

RESULTS

The results of the evaluation of inflation pressure vs. interface or seating pressure for the Gaymar Sof-Care Cushion are shown in Figure 1. The Thin, Average, and Overweight body builds are represented by an average individual from each category. The characteristic curve for each is similar, with lower interface and internal pressures found in the thin category followed by average and overweight categories.

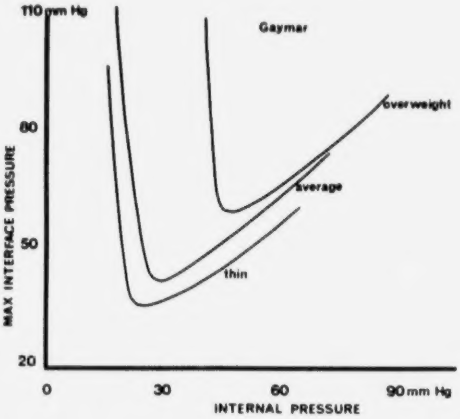

Figure 1

*Norms for body types taken from Scientific Tables, Documenta Geigy, 6th edition, 1962, "Average Weights for Adults".

Figure 2 compares the relative interface vs. relative inflation pressures for the three air cushions being studied - the Gaymar Sof Care, Bye-Bye Decubiti (BBD), and ROHO. The three curves are superimposed to illustrate their respective sensitivty to under or overinflation. The three curves exhibit a typical pattern with the Gaymar cushion being slightly more sensitive to under-inflation.

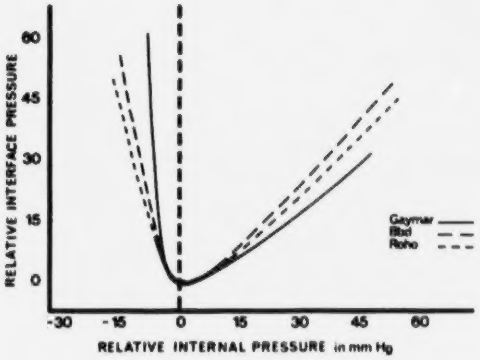

Figure 2

The relationship between interface pressure and body weight on the Gaymar cushion is displayed in Figure 3. The least squares method was used in obtaining the linear representation. However, there is a large scatter of the data points with only a slight correlation existing between the two variables.

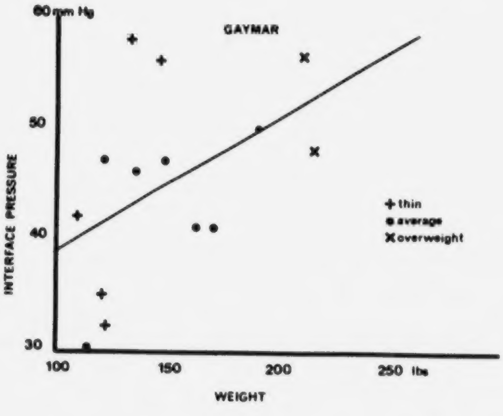

Figure 3

Figure 4 illustrates how many individuals can be satisfactorily served with a universal inflation pressure. The percent with satisfactory interface pressure was determined in the following manner: the minimum interface pressures (refer to Figure 1) was increased by 8 mm Hg and the corresponding inflation pressure range was defined. The percent of the cases with interface pressures within 8mm Hg of their optimal pressure was calculated and plotted for each corresponding inflation pressure. At 35 mm Hg 85.7% of the individuals tested met this criterion. It should be noted that even the two individuals who did not meet the criterion had seating pressures under 60 mm Hg.

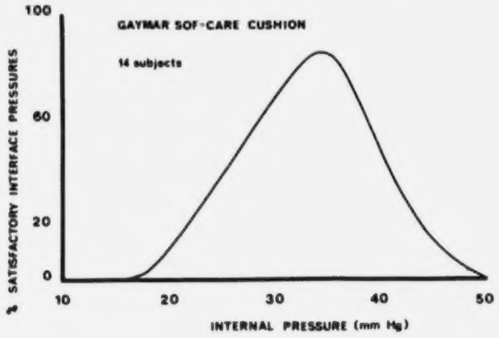

Figure 4

DISCUSSION

Figure 1 clearly displays the effects of over or under inflation of the Gaymar air filled wheelchair cushion for the three main body types - thin, average, and overweight. The cushion is much more sensitive to under inflation as noted by the sharper slope to the left of the minimum of the curve. The rapid increase in interface pressure associated with a small change in inflation pressure graphically demonstrates the effect of "bottoming out". The cushion is less sensitive to over inflation noting that the maximum pressure exceeds the minimum obtainable by 25-30 mm Hg when the cushion is over inflated by 40 mm Hg.

Similar curves were derived for the other body types (see Figure 1). For the three typical subjects, seating pressure was lowest in the thin individual, followed by the average and overweight subjects. However this trend in seating pressures is disproved in Figure 3 which illustrates no signicant correlation between body weight or body build and seating pressure. This information is a reflection of what is seen clinically where many other variables are seen to influence seating pressures. Some of these factors include the degree of prominence of the ishium or trochanters, the weight and length of lower extremities, posture in the wheelchair, and height(3).

The characteristics of the three air cushions (Bye-Bye Decubiti, Gaymar Sof Care, and ROHO) are shown graphically in Figure 2. Again, the curves are similar with some variation in the sensitivity to either over or under inflation. The Gaymar cushion which consists of three heat sealed layers of PVC, is extremely sensitive to under inflation, while the structures of the ROHO and Bye-Bye Decubiti cushions offer some support even when not sufficiently inflated. This is especially true of the individual cell structure and material of the ROHO. In all three cushions less sensitivity to over inflation is displayed. The Gaymar shows the least sensitivity followed by the ROHO and Bye-Bye Decubiti respectively. The range for optimal seating pressures is fairly precise, - only 6 mm Hg. Figure 2 also demonstrates the importance of maintaining the proper amount of air in the cushions in order to benefit from its pressure relieving characteristics. The data also suggests that while over inflation does induce higher seating pressure it is less dangerous than under inflation. The need for a pressure indicator which alerts the consumer when the cushions pressure falls above or below a preset level is clearly shown here.

In the design of such a pressure indicator system, a careful analysis of acceptable inflation air pressures must be made. Figure 4 displays such an analysis for the Gaymar cushion. With an inflation pressure of 35 mm Hg. 12 out of 14, or 85.7%, of the subjects tested had satisfactory seating pressures (i.e. within 8 mm Hg. of their lowest interface pressure). This information is valuable as a criterion in an inflation pressure indicator which will effectively monitor the seating pressure for a large population of consumers. An alternative approach may be to design a system which can be set at an inflation pressure correlating to the individual's body weight There is a direct relationship between weight and internal pressure; this may be expressed as inflation pressure = 0.165(wt. in lbs) + 4.5. (mm Hg.)

CONCLUSIONS

Based on the objectives and results of this study the following conclusions may be made:

1. Seating pressures are dependent on the inflation pressure. In all three of the air cushions tested, under inflation produced a greater sensitivity than over inflation. This implies that the over inflated cushion is more effective in reducing interface pressure than the under inflated cushion.

2. The results indicate a need for a careful clinical evaluation in the prescription of air filled wheelchair cushions. An individual who does not demonstrate a high degree of personal responsibility is not a good candicate for an air cushion. A conscientious effort must be made by the consumer to maintain the inflation pressure of the cushion in order to assure maximum protection.

3. Thirty five mm Hg. was found to be an effective inflation pressure for all of the fourteen subjects tested in this study.

4. No correlation was found between weight and interface pressure; but the ideal inflation pressure appears to be directly related to the user's weight.

5. All three air cushions under evaluation proved to be effective in reducing the interface pressure. Air filled cushions are a viable alternative to foam cushions and will become even more useful if and when an indicator system becomes available to monitor inflation pressure.

6. The construction material and geometry of the air cushion are important variables and affect the performance as defined by the cushion's sensitivity to over or under inflation.

ACKNOWLEDGEMENT

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REFERENCES

1. Garber, S.L., "A Classification of Wheelchair Seating", American Journal of Occupational Therapy, 33: 652-654, 1979.

2. Garber, S.L., Krouskop, T.A., Carter, R.E., "A System for Clinically Evaluating Wheelchair Pressure Relief Cushions. American Journal of Occupational Therapy, 32: 565-570, 1978.

3. 1982 Annual Report, Texas Rehabilitation Engineering Center, Baylor College of Medicine, NIHR Grant G008200043.

Rebecca Williams, M.Eng.
Baylor College of Medicine
TIRR-REC
1333 Moursund Ave.
Houston, Texas 77030

7.9

THE RESPONSE OF POLYURETHANE FOAM WHEELCHAIR CUSHIONS TO ENVIRONMENTAL AGING

Philip C. Noble, M.S., Baylor College of Medicine
Barry L. Goode, M.S., Baylor College of Medicine
Thomas A. Krouskop, Ph.D., Baylor College of Medicine
Barbara Crisp, The Institute for Rehabilitation & Research

INTRODUCTION

Wheelchair cushions fabricated from polyurethane foams are extensively used by individuals with sensory impairment to prevent the occurrence of pressure sores over the buttocks during sitting.(1) Clinical experience however has shown that foam wheelchair cushions are associated with a relatively high incidence of pressure sores, due in most cases to the deterioration of these cushions with use.(2) Polyurethane wheelchair cushions typically soften within the first month of use and are often observed to have lost a significant proportion of their initial hardness at intermediate matrix deformation and under impact loading conditions. Changes of this nature compromise the pressure redistributing properties of cushions and lead to the elevation of body/cushion interface pressures beyond safe limits, particularly over the bony areas of the buttocks. Traditionally, changes in the loadbearing properties of the foam cushions have been attributed primarily to the effects of repetitive compressive loading leading to fatigue softening of the polymeric matrix(4). This study examines the possible contribution of environmental aging and exposure to ultraviolet light in the outdoor environment to the softening phenomenon.

MATERIALS AND METHODS

Nine polyurethane foams commonly employed in the fabrication of mattresses and wheelchair cushions were selected with densities ranging from 1.3 to 3.6 lb/ft^3 and hardnesses of approximately 30 to 70 lbs (25% ILD). Test pieces measuring 6 inches x 6 inches were prepared, some being 4 inches and others 3 inches in thickness. Two identical test pieces were prepared from each polyurethane foam, one test piece being covered with a stretch fabric commonly employed in the manufacture of cushion covers. Prior testing demonstrated that the cushion covering reduced the intensity of sunlight incident upon the surface of the foam to approximately 10% of ambient levels in a range of outdoor conditions. In each case the duplicate test piece was left uncovered. The total array of eighteen test pieces were suspended from a rack in the outdoor environment at Houston for a period of six months from April to October, 1982. At the commencement of the aging period and at regular intervals thereafter, the hardness of each test piece was measured using a 2 inch diameter indentor which deformed each test piece to an indentation depth equivalent to 50% of its initial thickness. At the completion of the exposure period, all specimens were examined for evidence of surface changes and degradation.

RESULTS

Superficial examination of the test pieces at the conclusion of the environmental aging revealed marked differences between test pieces which had been covered in comparison with their uncovered counterparts. The bare test pieces had been discolored to a depth of approximately 1/4", the surface layers in some cases crumbling during examination. In comparison with its covered pair, each bare test piece displayed a loss in thickness, which averaged 7% (range: 0-17%) without a corresponding change in density which suggested that surface loss of polymer occurred during exposure of the uncovered test pieces.

The indentation force data was found to vary markedly with duration of aging, all test pieces displaying the same basic pattern of hardness changes.
In each case the foams hardened significantly over the first 10 days, returning to around the initial hardness after the third week of environmental exposure. A relatively stable level of indentation resistance was then maintained from the sixth to the thirteenth week of aging followed by an abrupt loss of hardness which continued with a gradual softening of each test piece until the conclusion of the experiment. The individual sets of hardness data were characterized by five variables: the initial hardness, the maximum hardness measured during aging, the mean hardness measured during the second month and the fifth and sixth months and the time taken for the hardness to drop to 80% of the initial value.

Based upon these parameters, no significant difference was found between the properties of the covered test pieces with respect to their uncovered counterparts. The individual indentation resistance vs. time profiles however were found to fall into two distinct patterns. Nine of the test pieces (Fig. 1, group A) displayed a substantial initial rise in indentation resistance which averaged 58% of the initial hardness while the nine remaining test pieces hardened less significantly to only 20% of their initial value (Figure 1, group B). This effectively increased the hardness of all group A test pieces for the duration of the entire aging procedure with respect to group B. Analysis of factors characterizing the test pieces demonstrated a highly significant difference (p 0.001) between the initial indentation resistance of the two groups, group A foams having a mean ILD (25%) of 431b (range 33-531b) in comparison with 581b for group B (range 52-681b). Thus softer foams were observed to harden dramatically during the initial states of aging in comparison with the harder foams leading to the observation that for most of the period of environmental exposure, the indentation resistance of "hard" and "soft" test pieces were actually very similar, the softness of some test pieces being susceptible to loss with very little aging.

In terms of wheelchair cushion performance, loss of hardness after prolonged cushion use is of particular importance. It was observed that a broad range of hardness changes were present during the second month of aging of the test pieces, and to a lesser degree during the two months prior to the conclusion of the experiment. Consequently, a multivariate statistical analysis was performed relating the degree of softening (normalized with respect to to the initial hardness) to variables characterizing the initial test pieces, in particular the foam density, initial indentation resistance and thickness of the test pieces.

The change in hardness at two months ranged from +24% to -33% (mean: -6%) and was found to be significantly correlated with all three variables particularly the initial hardness. Foams which softened most with aging were found to be primarily of greatest initial hardness and secondarily of low density. The combination of higher density (i.e. 2.5 - 3.5 $lb.ft^3$) and lower initial hardness (i.e. 25 - 35 lb. at 25% ILD) was associated with a reduction of softening of up to 50% after two months exposure. In contrast, hardness changes after six months correlated less significantly with variables characterizing the foams initially. At this point hardnesses varied from +9% to -43% (mean -28%) and were only significantly influenced by the initial foam hardness independent of density and thickness. Foams which were hardest initially were found to soften most, hardness differences accounting for a range of 32% in the loss of indentation resistance after six months of exposure.

DISCUSSION

Foam wheelchair cushions and mattresses often deteriorate with use leading to a loss of hardness typically amounting to 50% over a 3-6 month period. This change in loadbearing properties has often been attributed to "fatigue softening" associated with repetitive indentation of the polymeric matrix, although laboratory test simulating this mode of loading generally lead to smaller changes in indentation resistance than those observed in practice.(4) Moreover the loss of hardness caused by repetitive loading is observed to occur early in the life of cushions and mattresses and not after some weeks or months of continued use. Laboratory studies have also demonstrated the resistance of polyurethane foams to fatigue softening to be strongly dependent upon the density of the matrix rather than the initial indentation resistance. It may be hypothesized that the difference between laboratory studies and the experience of wheelchair cushion user is attributable to several additional influences upon foam properties which are not present during conventional laboratory testing. These include the presence of a humid environment, exposure of foam cushions to ultraviolet light, prolonged compression of cushions as distinct from continual repetitive flexing and inherent aging processes within the polymeric matrix itself.(5)

The results of this study suggest that mechanical deformation, whether continuous or repetitive is not required to explain much of the deterioration of foam wheelchair cushions observed in service. Ultraviolet exposure is probably not a primary factor, it seems that oxidation may be a much more critical factor. In some cushions, ultraviolet light may be responsible for surface deterioration leading to accelerated breakdown through wear and attrition of surface layers. For this reason cushion covers are useful in prolonging cushion life and maintaining the size and thickness of the polymeric core.

The results of this preliminary study suggest that most polyurethane foams used for seating applications are inherently unstable in conditions of environmental exposure and are likely to undergo substantial degradation of loadbearing properties after several months service, regardless of the frequency or severity of use. This effect however may be minimized by correct foam selection. Most importantly, although most foam products ultimately become unserviceable in wheelchair use, the impact of aging upon foam cushions over a large proportion of cushion life may be greatly reduced through selection of foams of highest practicable density in combination with relatively low hardness. In practice it is expected that the service performance of foam wheelchair cushions will be the combined effect of softening due to repetitive loading and the aging effects examined in this study. Only carefully controlled field and laboratory testing will reveal the relative influences of these mechanisms under a range of climatic and usage conditions. It is known however than density of the urethane matrix strongly influences resistance of cushions to fatigue and aging influences upon the matrix. An alternative approach may be the adoption of processes to mechanically or environmentally pre-age foam cushions before use. This may allow the use of foams of greater density and hardness than has been customary in wheelchair cushions in the past while still minimizing long term deterioration and the disturbing incidence of skin ulceration to which this phenomenon leads.

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REFERENCES

1. Noble, P.C., "The Prevention of Pressure Sores in Persons with Spinal Cord Injuries", World Rehab. Fund, Intl. Exchange of Information on Rehab., Monograph No. 11, 1981.
2. Garber, S.L., Krouskop, T.A. and Noble, P.C., "The Effectiveness of Preventive Management in Reducing the Occurrence of Pressure Sores", Proceedings of the 5th Annual Conference on Rehabilitation Engineering, 1982, p. 85.
3. Denne, W. and Molden, F., "Fatigue in Polyurethane Foam", Oxford Orthopaedic Engineering Center, Annual Report 1978, pp. 46-49.
4. Marchant, R.P., "Comparison of Polyurethane and Latex Foams for Furniture", J. Cellular Plastics, pp. 85-89, 1982.
5. McFadyen, F.M. and Stoner, D.L., "Polyurethane Wheelchair Cushions: Retention of Supportive Properties", Arch. Phys. Med. Rehab., Vol. 61, pp. 234-237.

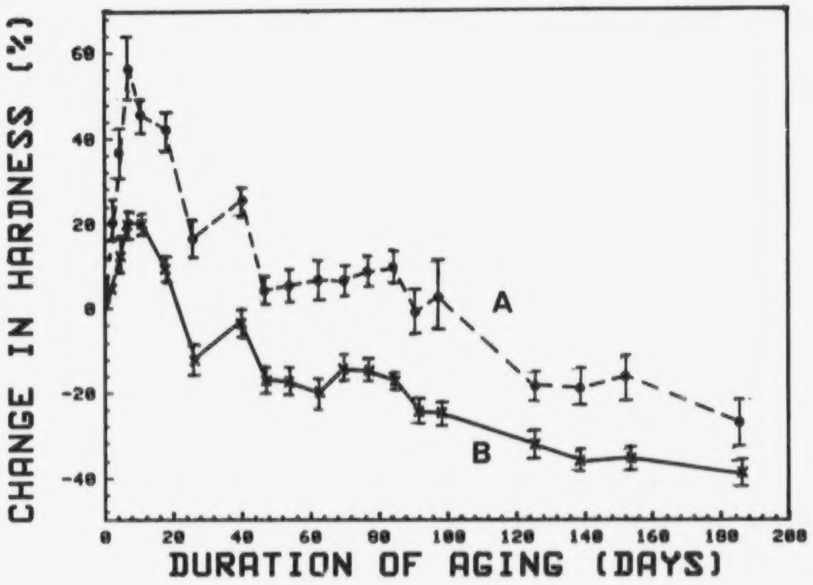

Figure 1

Philip C. Noble, M.S.
Department of Rehabilitation Engineering
Baylor College of Medicine
1333 Moursund Ave.
Houston, Texas 77030

SYSTEMATIC ASSESSMENT OF KEY FACTORS TO PRESCRIBE SINGLE-INPUT INTERFACE CONTROLS

F.Shein, M.Eng.,P.Eng., K. Lee, B.Sc.O.T., & M. Milner,+ Ph.D.,P.Eng.,C.C.E.
Rehabilitation Engineering Department, Ontario Crippled Children's Centre
350 Rumsey Road, Toronto, Ontatio, M4G 1R8
(+ and Institute of Biomedical Engineering, University of Toronto)

ABSTRACT

A systematic procedure for the identification of the most appropriate control scheme for single-input interfaces has been developed. Building on procedures derived from assessments developed by others, a concept, coined MSIP meaning Movement; Site; Interface; and Position is advanced. Objective evaluations and comparisons of MSIPs are achieved through microcomputer-based assessment techniques utilizing an APPLE II microcomputer. The relevant performance tasks and results accruing from 25 subjects with cerebral palsy are discussed and described.

INTRODUCTION

In recent years, microcomputer technology has made significant inroads towards helping the physically disabled in many areas such as rehabilitation, vocation, education and leisure. By means of cleverly designed and placed switches, persons with the functional loss of hand, arm or other limb movements can now interact with and use a microcomputer. Many different types of switches or interfaces are available; some using simple technology such as a flap switch and others using advanced electronic technology such as EMG switches.

In parallel with the development of special interfaces has been the design of various input strategies that greatly facilitate the interactions of a disabled person with a microcomputer when only a single or a few switches are used.

Considerable effort has been devoted to single-input access. Literally dozens of single switches are now available including mechanical touch pads, leaf and lever switches, pneumatic switches, EMG switches, capacitive touch-plates and interruptable light beams.

Underlying all of these special input techniques is the need to identify the most appropriate body movement(s) associated with the control operation; the body site that actuates the controller; the interface; and the position of the interface. In the course of our research, we have given these factors the acronym MSIP to represent Movement; Site; Interface; and Position. Although technology has provided great potential, major problems still arise in pinpointing effective MSIPs with severely physically disabled persons, especially those with cerebral palsy.

It is known that the determination of the most effective MSIP(s) is through systematic and thorough assessment. Further, objective determination is to be preferred. Inherent in this assessment must be the recognition of the end task to be performed since that affects the selection of an MSIP. For example, an entirely different MSIP may be called for if the task requires maintained activation of a controller instead of momentary contact.

Interface assessment protocols have been developed (Coleman, Cook, & Myers, 1980; Barker & Cook, 1981) that take cognizance of the concepts mentioned above. This background has been of value to us. In 1980, researchers at the Ontario Children's Centre began testing computer-based evaluation techniques in conjunction with assessments of powered mobility interfaces (Basacchi, Naumann, & Milner, 1981). More recently, research has been undertaken to develop a systematic assessments procedure for the prescription of single-input MSIPs primarily for use with a microcomputer. The protocol developed is summarized in this paper. Focus has been placed on single-input modes since they form the simplest control model; yet complex problems still surround their use by severely disabled persons. To date, 25 clients (5-21 years old) have been assessed and it is anticipated that another 11 will be seen before completion of the project.

ASSESSMENT PROCEDURE

There are 2 parts to the assessment. Firstly, the initial assessment to determine 3 possible MSIPs. This is carried out by a team consisting of a therapist knowledgeable in interfaces and their use, the client's therapist, a technical person, and an instructor or aide. Secondly, the objective comparison of MSIPs by monitoring performance in specific tasks on the microcomputer.

Client Criteria

All clients participating in the study are physically disabled with severe quadriplegic involvement. None are able to operate a conventional or even modified keyboard. Although there is the possibility that some clients could use multiple switches, the first step to be achieved is functional control over one switch. Prior to assessment, proper postural seating support was arranged and it was ensured that all could understand the tasks involved.

Part 1 - MSIP Selection

When investigating single-input modes that a client can use to activate a microcomputer, all four factors-the movement pattern; the control site; the interface; and positioning of that interface must be evaluated. In the final decision concerning the most efficient MSIP, all these factors must be well defined since in our experience a slight change in any one of the four factors may greatly alter the client's performance. Part 1 of the assessment protocol is designed to assist the clinician in carrying out this process in a systematic way. The six sections to this part are highlighted below:

(a) Background Information: To be completed by the "home" team of professionals (those familiar with the client), this section summarizes information relating to the client's behaviour, physical and functional skills, communication, and previous experience with control systems.

(b) Seating and posture: The client's seating system is examined to ensure a stable and functional posture for maximal performance.

(c) (M) Movement patterns: All body movements are assessed systematically, starting with the hands (which are traditionally used for manipulation), then the arms, the head, and the lower limbs. Efficient movements are those that the client can initiate, control, and return to the resting position. It is important to note the effect of a movement on the client's muscle tone, abnormal reflexes, and positioning. The use of any stabilizers to assist the client in completing a movement is recorded.

(d) (S) Control Site: Body sites within efficient movement patterns are evaluated with regards to the best contact with potential interfaces. For example, the client can use either the side or palm of the hand to activate a switch, while sliding an extended arm to the switch.

(e) (I) Interface: Judgements are first made to determine the type of interface most appropriate at each control site. Selection from a group of interfaces is then made by considering such factors as size, sensitivity, feedback (tactile, proprioceptive and auditory), ease of set-up, cost, durability, and reliability.

(f) (P) Position of interface: Approximate positioning of the interface is suggested by M, S, and I. Exact positioning is then determined by the client's performance with the interface at different placements using computer tasks outlined in Part 2. Repetition of these tasks with the interface placed in a number of positions is made over 3 sessions (Note - this is separate from part 2).

Throughout the determination of the MSIPs meaningful and motivating functional activities are used to elicit maximum performance. To this end, electric toys and simple computer games have been employed.

It must be noted that determination of individual MSIP factors cannot be made without the consideration of the other factors.

Part 2 - Performance Tasks

In this part the client performs 3 different functional tasks on the microcomputer (APPLE II, 48K) using each of the MSIPs selected previously, for 5 sessions. Repeated measurements are necessary to allow accomodation by the client to each MSIP which may be new to him/ her, and to account for variability in performance which is prevalent with persons having cerebral palsy. On the other hand, too many sessions of repeated tasks can lead to boredom and poor performance. This was demonstrated in a pilot project with a group of 9 children.

(a) Task 1 (Response Time): In this task the client must respond to a visual stimulus on the monitor by activating the interface as quickly as possible. Ten stimuli are presented in random intervals that vary between 1 and 3 seconds. Response times in hundredths of seconds are recorded as are the numbers of times the interface is activated prior to the stimulus appearing (prehit). The hypothesis is that the best MSIP will have the lowest response time with fewest prehits.

(b) Task 2 (Autoscan): This task consists of repeatedly selecting a coloured box that sits above 1 of 5 horizontal lines that are displayed on the monitor. A cursor scans below and across the lines and when it appears below the target box, the client must activate the interface. There are 4 sets of trials with each set having progressively faster scanning rates of 4, 2, 1 and 0.5 seconds. In order to move from one set to the next the client must obtain 3 cumulative correct selections with that set. If 3 cumulative errors occur, the task ends. This task determines the ability to respond to a simple scanning situation where anticipation is possible. The hypothesis is that the best MSIP will allow the fastest scanning rate.

(c) Task 3 (Hold/Release): The client must maintain activation of the interface for set periods and desist at the end of the period in this task. Using similar logic to Task 2, there are 3 sets of trials where the holding time increases in each set (2, 4 and 6 seconds). To move from one set to the next, 3 cumulative correctly maintained activations must be achieved. However, 6 attempts at maintaining are allowed before an error is registered although the numbers of attempts and activation times are recorded. To facilitate this task, a 'flame' is drawn on the monitor shooting towards a target box that is positioned 2, 4, or 6 seconds away depending upon the trial set. Release time is monitored from when the 'flame' reaches the target, and the client is cued to release as fast as possible. A maximum 4-second release time is allowed.

Each task is available in both practice and test modes. In the test mode, data is automatically stored on floppy diskette. Data can be retrieved through display and summary programs that are included in the total software assessment package.

One example of collected data is shown below in Figure 1.

During the course of this part of the assessment it is important for the instructor or aide who is working with the client to provide full instructions and allow sufficient time to practice prescribed movements. It is also their responsibility to note the client's behaviour (eg. alertness, state of health, cooperativeness, and anxiety); deviations in prescribed control movements; effects of performance on body tone, reflexes, and positioning; and eye-contact with the monitor during the tasks.

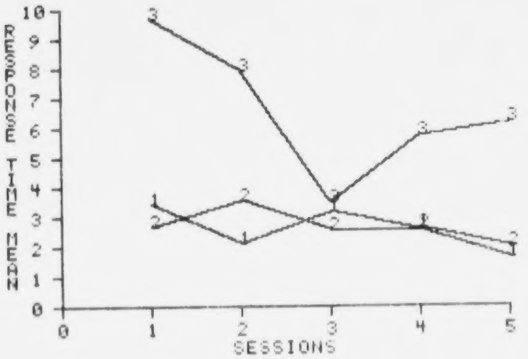

Figure 1: Typical summary of results from 5 sessions for a client showing the mean of 10 response times for Task 1 for 3 MSIPs (1, 2, and 3).

DISCUSSION AND CONCLUSIONS

Of the sixteen clients assessed after the initial pilot group, all but one could be prescribed with at least one functional single-input MSIP. Functionality, in terms of the performance tasks, is defined as reliable volitional control. One of the purposes of this project is to categorize functionality in terms of performance. This will be reported on at a later date.

Results show that some second and third rated MSIPs had more potential than initially thought, and in a few instances were more efficient than the initally preferred MSIP. Results also demonstrate that some MSIPs are more suited to a particular task such as simple contact activation in contrast with another task such as maintained contact.

From this assessment a single-input mode is identified which provides a starting point in training the client in actual computer use. In addition, training can also be provided with the other MSIPs in the anticipation that performance with them will improve sufficiently so that they may be used in future multiple-input modes.

The importance of a systematic and thorough investigation of all the factors of MSIPs needs to be emphasized when determining potential single-input modes for severely physically handicapped persons. A valuable tool in this process is the microcomputer since it provides quantitative data on the client's performance thereby allowing objective comparisons between different MSIPs to be made. The microcomputer also allows simulations of actual functional activities.

The final decision regarding the most efficient MSIP is determined by both the quantitative data and the qualitative data or clinical observations. It is our view that the incorporation of systematic measurement techniques to measure performance of clients in the context of this paper, has the potential to provide an almost indispensable aid for the therapist.

ACKNOWLEDGEMENTS

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REFERENCES

Barker, M.R. & Cook, A.M. A systematic approach to evaluating physical ability for control of assistive devices. Proceedings of the 4th Annual Conference on Rehabilitation Engineering Washington, D.C., 1981, 287-289.

Basacchi, A., Naumann, S., & Milner, M. Microcomputer based assessment of controller interfaces for disabled users. Proceedings of the 4th Annual Conference on Rehabilitation Engineering Washington, D.C., 1981, 295-297.

Coleman, C.L., Cook, A.M. & Myers, L.S. Assessing non-oral clients for assistive communication devices. Journal of Speech and Hearing Disorders, 1980, 45, 515-526.

Ontario Crippled Children's Centre
350 Rumsey Road,
Toronto, Ontario,
M4G 1R8

8.2

The Use of Control Interface Devices with Multihandicapped Individuals with Cognitive Dysfunction

Philippa H. Campbell
William F. Mc Inerney

Children's Hospital Medical Center of Akron

ABSTRACT

Single subject designs were used to validate the effectiveness of assessment and training strategies used to teach multihandicapped children with severe brain damage and cognitive dysfunction to operate switching devices to control aspects of their environments. Cueing strategies, varied across participants for individual patterns of sensory, motor, and cognitive dysfunction show promise as a means for training selective and intentional control of the physical environment.

INTRODUCTION

Increased survival rates for both badly damaged infants and head trauma patients are producing greater numbers of severely multihandicapped individuals requiring rehabilitation and education. In addition, public attitudes and laws (such as the Education for All Handicapped Children's Act) have made services more readily available for severely cognitively limited individuals. However, because of the number of handicaps and the severity of brain damage, many individuals are unable to participate in traditional rehabilitation and education programs. In addition, standard intellectual assessment protocols are often invalid or produce information that is meaningless relative to education and rehabilitation training. The utilization of a range of electronic environmental control devices in systematic application can minimize the effects of motor dysfunction to both reliably observe intellectual skills and train cognitive abilities.

BACKGROUND

Applications of rehabilitation engineering technology to the problems of multihandicapped children have largely centered on cognitively intact children with severe motor dysfunction (6), (11). Recently, some limited attempts have been made to use simple electronic control interfaces to provide significantly impaired multihandicapped children with "meaningful" activity (4), (7), (10) Few attempts have been made to use interface operation either to determine cognitive ability (3), (4) or to train acquisition of cognitive skills (5).

Simple cognitive abilities (i.e. sensorimotor) derive from an orderly progression of successively more complex organizations of motor responses that range from reflexive responses to sequences of two or more movement schemes (patterns) in ways that solve a particular enviornmental "problem" (8). An individual must be able to demonstrate a specific movement at a known rate, perform that movement under stimulus control of a given set of environmental conditions, and, at the most complex level, sequence that movement with another that is also performed under stimulus control (5). A given motorically impaired individual, in clinical application, must for instance, tip the head forward to start a communication scanning device but not tip the head forward when the scanning device is not present. The specific movement, head forward, must be under stimulus control of the scanner. Subsequently, the individual must also be able to perform an alternate response, such as bring the head back into alignment, to stop the scanning action. The second movement must also be under stimulus control such as, in this example, the symbol or picture represented on the communication device. However, to use the device to intentionally communicate, both movements must be sequenced together to solve the "problem" of indicating a need, idea, or feeling represented on the scanner.

This 3-level sequence of cognitive skills provides the basis for training of cognitive skills described in this paper where level 1 represents strengthening a given response, level 2 achieves discriminated performance of a particular movement (stimulus control) and level 3 sequences 2 or more discriminated movements to solve an environmental "problem."

MATERIALS AND METHODS

A range of switch interfaces, commercially available (9) or individually fabricated (2) were selected and matched to the motor competencies of participating students and used in conjunction with electronic data counters and 110 volt control units (5) that allowed interfaces with student preferred consequences to increase movement rate (level 1) and teach discrimination abilities (level 2) and sequences of movement responses (level 3).

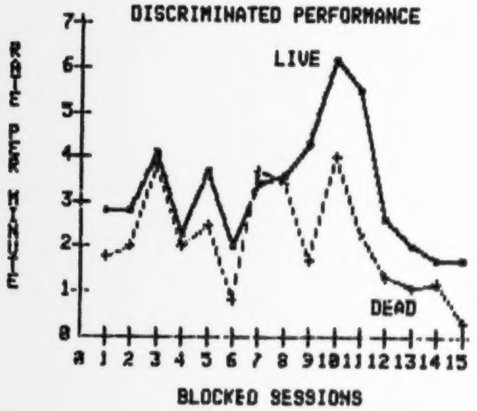
Specific techniques for training stimulus control, discrimination, and movement sequences were derived from applied behavior analysis procedures (e.g. 1) and were individually evaluated for effectiveness on the basis of performance data for each participating student. Strategies included physical guidance, shaping, and differential reinforcement of other behavior (DRO).

Single subject data from 4 students illustrate use of the training sequence. All 4 students were diagnosed as multihandicapped with motor dysfunction (cerebral palsy) as one of the handicapping conditions. Two students were blind. All were profoundly mentally retarded as determined by standard tests of intelligence. Chronological ages ranged from 4.4 to 14.7 years at the time of training. Three students were trained to activate devices for environmental control. One student, the youngest, was taught to use a joy stick interface for mobility in an electric wheelchair.

RESULTS

Appropriate statistical tests were used to determine differences in mean performance with switch activation in various training levels and with individualized training strategies. Results showed significant differences for individuals when performance in baseline (no training) and training conditions were compared.

The following graph presents data from one of the participating students to illustrate training at level 2, discrimination, where response rate was brought under differential stimulus control.



This 8.6 year old student was cerebral palsied and blind with an estimated mental age of 3 months. Activation of a barrel switch interface was selected (level 1) and performance was strengthened using music as a reinforcer. Discrimination (level 2) was achieved, using DRO strategies, by presenting 2 barrel switches, one cued with sandpaper ("live") and one non-cued in a randomized, counterbalanced paradigm. Activation of the cued switch, regardless of position, always produced music. Overall rate of activation decreased across sessions, possibly due to habituation. However, differential rates of activation between "live" and "dead" conditions showed significant differences in discriminative activation rates.

Data obtained from implementation of the same training methods with 3 other students at levels 1, 2, and 3 showed similar effectiveness in training cognitive skills using control interface devices.

DISCUSSION

Traditional approaches to application of rehabilitation engineering technology in treatment of handicapped populations have relied on already present and sufficient cognitive competence to operate devices fabricated to overcome specific motor or sensory limitations. Results from our studies with multihandicapped, severely brain damaged children indicate that switch interface control devices, in combination with specific training of cognitive skills, can not only increase cognitive skills but also allow individuals with severe cognitive impairment to operate switch interfaces to intentionally control aspects of the physical environment.

The training sequence is probably also applicable with other handicapped populations with cognitive dysfunction (e.g. head trauma patients). However, the training process must be initiated by interfacing the handicapped person with a device that is easily operable by a movement that is already present in the repertoire and that, when activated, produces an outcome that is known to be reinforcing for the individual. Therefore, specific training aspects must be individually designed. Performance data must be taken throughout training and used by the trainer to assess effectiveness on an ongoing basis. This is particularly true for severely multihandicapped individuals where factors such as state, medication levels, and habituation (such as illustrated earlier) may impact on the overall training process. Regular review and interpretation of data allows the trainer to make adjustments in training strategies and reinforcement outcomes.

ACKNOWLEDGMENTS

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REFERENCES

(1) Alberto, P.A. & Troutman, A.C. Applied behavior analysis. Baltimore: University Park Press, 1982.
(2) Burkhart, L.J. More homemade battery devices for severely handicapped children. College Park, Maryland: private publication, 1982.
(3) Brinker, R.P. & Lewis, M. Making the world work with microcomputers. Exceptional Children, 1982, 49, 163-172.
(4) Campbell, P.H., Bricker, W., & Esposito, L. Technology in the education of the severely handicapped. In Quality education for the severely handicapped. Washington: U.S. Office of Education, 1980.
(5) Campbell, P.H., McInerney, W., & Middleton, M. Using technological devices to train severely handicapped students. Akron: Children's Hospital, 1982.
(6) Herman, R.M. Augmented sensory feedback for children with cerebral palsy. Philadelphia: Kruzen Center, mimeographed, 1974.
(7) Inman, D.P. Gaining control of tension in spastic muscles. In Behavioral systems for the developmentally disabled. New York: Bruner/Mazel, 1979.
(8) Piaget, J. Origins of intelligence. New York: Norton, 1952.
(9) Prentke-Romich Company. Electronic aids for the severely handicapped. Shrve, Ohio, 1982.
(10) Tawney, J. Telecommunications for the severely handicapped: Final Report, University of Kentucky, 1979.
(11) Vanderheiden, G. Augumentative modes of communication for the severely speech & motor impaired. University of Wisconsin, 1979.

8.3

A MINIATURIZED UNIVERSAL INTERFACE MOBILITY CONTROL SYSTEM

E. Snell, C.E.T., M. Milner, Ph.D., P.Eng.,C.C.E.
Rehabilitation Engineering Department, Ontario Crippled Children's Centre

ABSTRACT

Commercial electric mobility systems generally operate via some form of joystick interface which may be active or passive. Neither of these interface types are readily adaptable for application with the more physically involved disability groups. This problem is related to the power control section of the electric wheelchair which has been designed for specific performance characteristics and a specific interface.

A miniaturized interface power control is being developed for the MPV (miniature powered vehicle)[1] that accommodates a wide range of interface inputs and provides sufficient power output capabilities to operate conventional sized mobility devices.

The present state of development and future developmental stages are described.

INTRODUCTION

The joystick interfaces most frequently used on commercial powered mobility devices can be divided into two groups.

The first, historically, is the active microswitch type joystick which switches the full motor operating current that can be in excess of 50A at switch closure. The system consists of four microswitches arranged in an "X" configuration that can be operated singly or in adjacent pairs.

The occurrence of high currents dictates that the switches be of relatively large physical size and that the motor/switch interconnect wiring be quite substantial. Also, a microswitch, upon closure, will provide a maximum acceleration condition up to maximum speed as determined by the motor characteristics. A similar situation occurs when the microswitch is opened but deceleration will be determined primarily by the electrical and mechanical motor damping factors. The system is, thus, relatively jerky in operation and creates a number of reflex, driver control, and mechanical problems. Adaptation of the control is limited to positional and actuator modifications.

The second joystick interface, a passive type and most commonly used, is the proportional control. This type is used in conjunction with an electronic motor control unit which decodes two voltage levels, proportional to the joystick position, into direction and speed information for the motors. The motor control unit is primarily designed to respond to this two voltage input whose response levels are peculiar to the particular manufacturer. Other types of switching systems could be made to simulate these voltage levels but models of the same switching system would have to correspond to the number of motor control types being utilized.

Acceleration and deceleration with proportional control is most frequently directly related to the rate of change of joystick position, and with an athetoid individual would responsively resemble the microswitch joystick. One attempt by a manufacturer to overcome this resulted in an interdependent acceleration/deceleration rate which in our experience is required to be independent. That is, a four second acceleration time may be required to compensate for the individuals athetoid movements, but a four second deceleration time would cause frequent collisions especially where perceptual impairment is involved.

The conventional proportional motor control unit, as described, does not readily lend itself to modification for use with the wide range of interfaces that may be required for various disability groups.

As a result of identifying specific problem areas with conventional electric wheelchair motor controls, interfacing systems, and the requirement for an interface motor control unit more proportionate in size to the MPV depicted in Figure 1, that the development of a universal interface power control unit was undertaken.

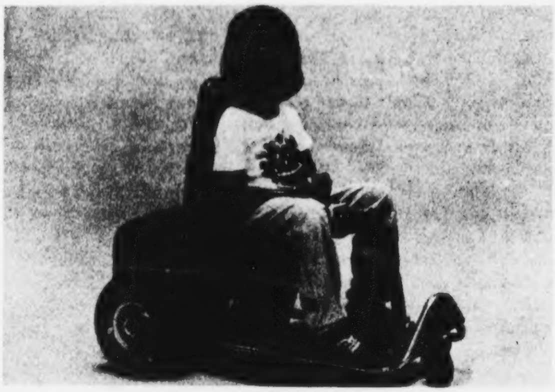

Figure 1: The MPV (miniature powered vehicle). A new electronic control system is being developed that will allow, diverse, alternative interfacing to the joystick.

Previous Experience

An Interface Programme was established at the Ontario Crippled Children's Centre (O.C.C.C.) in August, 1977, to provide alternatives to commercially available control systems primarily in the areas of mobility and communication. Adaptations to interfaces ranged from simple control box relocations or joystick extensions to the development and provision of more specialized interfaces such as a head position interface[2], capacitive touch plate interface[3], thumb control interface[4] and a scanning interface[5]. Although the types of interfaces were diverse, one item remained common to all in that an interface power control unit is required to convert the lower power (CMOS) interface logic levels to appropriate motor power levels. In May, 1980, a generalized interface power control was developed that incorporated a controlled rate of acceleration and speed control.

Whilst these units have proven satisfactory in regard to usage with regular commercially available wheelchairs, they are physically too large for direct application with the MPV and technical innovations have been identified to further improve the overall performance.

Design Criteria

Overview

To develop a miniaturized universal interface power control unit together with refinement and interfaces that will provide independent powered mobility through the MPV for children in the age range of 2 to 5 years who would otherwise be unable to achieve independent mobility.

Specifics

1. Interface identifier: There are two basic interface signal decoding strategies used with the existing interfaces dictated by the nature of the patient activated switching systems. To expedite and "fool proof" the interchangeability of the various interfaces the design should incorporate an interface identification system that will automatically select appropriate decoding. In this way a wide range of disability groups including cerebral palsy, muscular dystrophy and spinal muscular atrophy can be readily interfaced.

2. Independent Acceleration/Deceleration: Children who are particularly prone to a startle reflex or the detrimental factors associated with rapid acceleration and deceleration would definitely benefit from a controlled and adjustable rate of acceleration/deceleration. The differential between the acceleration and deceleration rate would vary with factors such as the physical involvement of the driver and the damping inherent in the mobility system. The deceleration rate of the MPV is quite rapid and is characteristic of the high ratio worm-gear drive system.

3. Thermal Shutdown: Due to the miniaturized size of the interface power control unit, the relative heat sinking area can not dissipate the heat developed by the continuous currents that could be encountered with the MPV. This situation occurs when children use the MPV to push obstacles or toys.

4. Motor Current Sensing Circuitry: The initial movement of a mobility device requires substantial motor current levels while actual normal run currents are an order of magnitude less. Current sensing circuitry will limit both, the peak currents to safe levels for PM motors and the output circuitry, and average currents to prevent excessive motor heat dissipation.

5. Independent of Supply Voltage: The circuitry should have adequate supply voltage insensitivity up to 30 VDC and a minimum of 10.0 VDC while still maintaining efficient operation.

6. Motor Speed Feedback: In the mass manufacture of electric motors used in wheelchair systems and those used on the MPV, it is usually difficult to obtain two motors which run at exactly the same speed under the same load conditions and applied potential. It is then apparent that driving in a straight line will require continuous control correction even over ideal terrain and becomes more apparent on irregular terrain, i.e. sidewalk slant. To overcome this an initial adjustment will be required to electrically alter the applied potential to the two motors which will compensate speed differences due to motor tolerances.

Secondly the BEMF (back electromotive force) generated by the motors should be measured and compared to an internal speed reference forming a closed loop speed control system.

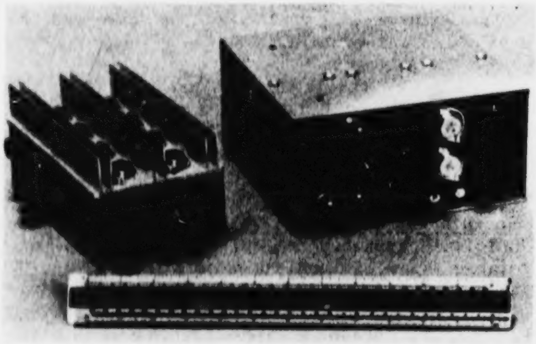

Figure 2: The MPV interface power control unit under development (foreground), is contrasted with the currently produced wheelchair model (background).

DEVELOPMENTS TO DATE

The MPV interface power control unit has been significantly reduced in size as illustrated in Figure 2 and incorporates the following features:

1. Interface Identifier - The selection of the appropriate decoding strategy was accomplished by using one of the interface input lines as an identifier. Connection of this line to Vcc (performed on the interface side) provided one selection while no connection provided the other.

The interface inputs are CMOS, active high, compatable with 100K pull down resistors and decoding is provided for 'X' or gated "T" joytick connections which are simulated for the other developed interfaces.

2. Independent Acceleration/Deceleration - Independent controls affecting both motors simultaneously provide continuous adjustment up to maximum acceleration and deacceleration times of approximately 4 seconds and 2 seconds respectively. Acceleration and deacceleration can be adjusted to minimum times that would simulate the responsiveness of a microswitch joystick while still having an adjustable speed control. In any case, deceleration circuitry inhibits a motor directional reversal, until deceleration is complete.

3. Thermal Shutdown - The continuous operating characteristic of the heat sinking area has been calculated for a 25°C temperature rise at a 25°C ambient temperature. This temperature rise allows continuous motor output current of approximately 7.0 A per motor and is independent of battery supply voltage due to the pulse width modulation technique utilized.

The shutdown temperature has been set at a 50°C heat sink temperature with a thermister lag time of 17 seconds. Thermal hysterisis has been incorporated and provides an automatic reset when the heat sink reaches 35°C.

Normal maximum continuous motor currents on the MPV with a 53 lb load are in the range of 4.0A per motor and would not be expected to create a thermal problem.

The maximum MPV stall currents are approximately 35.0A per motor which is well below the 50.0A per motor rated output current capabilities of the power control unit. The motors also have an integral thermal cutout.

4. Independent of Supply Voltage - The analogue and digital circuitry are operated from a voltage regulated supply down to a minimum of 10.0V battery voltage. The combination of power Mosfets and a Darlington bipolar power bridge motor outpout stage ensures continuous biasing independent of supply voltage.

PENDING DEVELOPMENTS

1. Motor Current Sensing Circuitry - Bifilar shunt resistors will be placed in the power bridge and, along with associated analogue circuitry, will generate signals for peak and average motor currents. These signals will be utilized to provide an OR'd output stage inhibit signal for the particular clock cycle in which the predetermined levels have been exceeded. The peak and average current inhibit levels will be controlled by the gain and the averaging time constant of the analogue current sense circuitry and can be set, as required, for the particular application.

2. Motor Speed Feedback - Differential analogue circuitry will measure the applied motor potential, the motor generated BEMF and in combination with the current sense circuitry a comparison will be made with the internal speed reference signal. The resultant of the comparison will be utilized to effect control over the average applied motor potential and, therefore, the motor speed.

3. Servicing Aspects - Once the design aspects have been finalised, the circuitry will be transferred to plug-in printed circuit boards. Appropriate physical and electronic schematics will be generated along with a technical service manual. The documentation would be on two technical levels that could provide support to technical and non-technical personnel. In this way it is expected that repairs could be performed in the general locales of usage, obviating the need to return units to the manufacturer.

CONCLUSION

The concept of a universal interface power control unit is not new but, through clinical identification of client related mobility needs, technical innovations have been incorporated in the MPV power control unit that will impact a wide range of disability groups. As information is gathered on the performance aspects of the MPV interface power control unit, the ensuing evaluation may identify research and development areas not yet addressed.

ACKNOWLEDGEMENTS

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The authors thank Grant Jung for assistance in constructing the first prototype.

REFERENCES:

1. Naumann, S., Walder, S., Snell, E., Milner, M., "A Powered Mobility Aid for the Two to Five year Olds with Neuromuscular Disorders", 5th Annual Conference or Rehabilitation Engineering, Houston, 1982, p. 74.

2. Literowich, W., Chau, G., Naumann, S., Milner, M., "A multi-interface wheelchair controller", proceedings of International Conference on Rehabilitation Engineering, Toronto, 1980, pp. 120-121.

3. Snell, E., "Capacitive Touch Plate Controller for Powered Mobility in Severe Motor Disability", 4th Annual Conference on Rehabilitaion Engineering, Washington, D.C., 1981, pp 69-71.

4. Snell, E., "Thumb Control Interface for Powered Mobility", 5th Annual Conference on Rehabilitation Engineering, Houston, 1982, p. 75.

5. Antczak, J., Snell, E, "Scanning Interface for Powered Mobility and Communication", submitted to the 6th Annual Conference on Rehabilitation Engineering, San Diego, 1983.

A SCANNING INTERFACE FOR POWERED MOBILITY AND COMMUNICATION

Antczak, J and Snell, E.
Rehabilitation Engineering Department, Ontario Crippled Children's Centre

INTRODUCTION

Conventional powered wheelchair joystick interfaces do not represent a viable mobility interfacing solution for the more physically involved individual, due to the degree of manual dexterity required for operation.

Numerous interfacing systems have been developed for the cerebral palsied population that utilize gross targeting techniques to access four or five carefully located switches associated with directional control. Previous experience has indicated that the capacitive touch plate interface[1] is readily adaptable to many reflex patterns, targeting requirements and force activation levels. However, repeated computer-aided interface assessments[2] with the particular individual who inspired the design of this system, indicated that currently available interfaces could not be optimized sufficiently to provide adequate access to mobility and communications.

A multidisciplinary team consisting of a physician, therapist and technologist performed an initial assessment to determine the individual's particular needs and abilities. This 17-year old female with cerebral palsy was diagnosed to be spastic, athetoid, quadraplegic and non-verbal. Aspects such as postural support, mobility, communication, environmental and physical abilities were considered by the team.

A subjective evaluation of her physical abilities indicated a reliable head rotational movement, but not of a nature that would allow the use of a head position interfaces due to the characteristics of the postural support system. Further evaluation indicated that some gross hand function was available and had been utilized to varying degrees of success in the past. As a result, the team generated a prescription to pursue the use of this gross hand function to activate capacitive touch-plate interfaces for mobility and communication.

Optimization of the interface position and size ensued over several 1-1/2 hr. sessions through the application of a software interface assessment technique[2]. Upon reviewing the accumulated data with this interface, we were able to determine that it did not represent an appropriate solution to our objectives. Reaction and total task times indicated that an enormous amount of energy and perseverance were required for relatively simple accessing (Figure 1). While some release times in excess of 5 seconds indicated a potential utilization hazard, at best we were able to find one or two interface switch positions that would be minimally suitable, but did not provide sufficient function for our five-switch interfacing system.

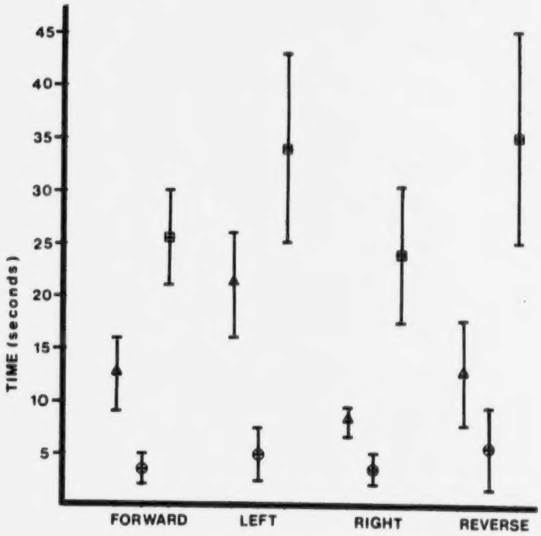

Figure 1

Average Reaction$^{\triangle}$, Release$^{\circ}$ and Total$^{\square}$ Times by Direction (Touch Plate Interface) Bars reflect standard deviations for final 3 trials

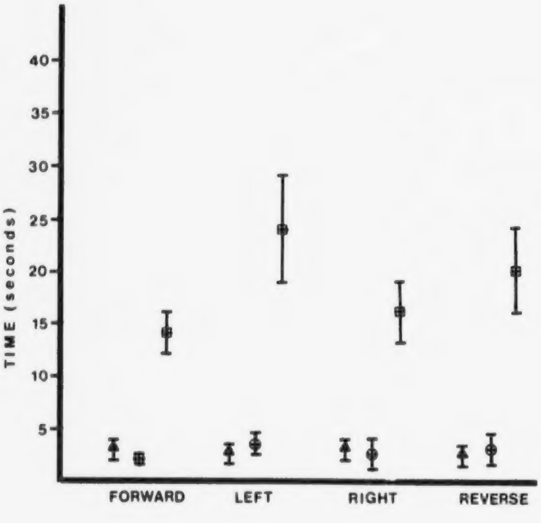

Figure 2

Average Reaction$^{\triangle}$, Release$^{\circ}$ and Total$^{\square}$ Times by Direction (Scanning Interface) Bars reflect standard deviations for the final 3 trials

SCANNING INTERFACE

Utilization of one or two switches to provide more than three functions requires that the intended functions be scanned in some manner and then the desired function selected. The hardware for the proposed system had not been developed and certain aspects of the design required clearer delineation.

THE SOFTWARE APPROACH

A software approach was used to generate a simulated scanning interface which, unlike the hardware approach, could be quickly modified and tailored to the individual's needs. Later, the final parameters of the software scanner were to be applied to the hardware design.

The software scanner required two switch inputs representing one switch for control of scanning the functions and the second switch for the selection of the function the scanner was stopped on. Finding two switch locations posed less of a problem than the five required for the previous interface and now allowed the application of good rotational head movements to facilitate interface assessments.

Another parameter of the software and hardware interface required that the switches provide both auditory feedback, because of built-in system time delays, and a soft texture to reduce tonal reflexes. The construction of these switches is illustrated in Figure 3.

Further assessments were performed using the interface assessment software and the scanning interface simulation to determine the degree of competence that could be obtained with interfaces. As can be seen from the summation of the assessment data in Figure 2, considerable improvements are evident in reaction release and total times for the same task. Moreover these improvements became more apparent when the hardware design was realized and the motivation of independent mobility was spurred by the promise of its realization.

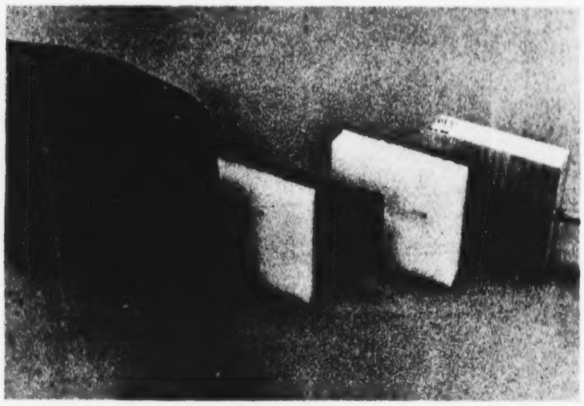

Figure 3

Foam Switch, Exploded View of Component Points

Figure 4

Illustration of the Completed Foam Switch

HARDWARE DESIGN CRITERIA

The design criteria of the overall system are summarized below:

1) The system would utilize two switches, as with the software system, which would perform "SCAN" and "SELECT" operations. The "SCAN" and "SELECT" inputs would be compatable with electro-mechanical and electronic switches that can provide a contact closure to ground or an active logic '0'.

2) The mobility and communication requirements had in common the scanning interface, lap-tray, and the postural support system. The powered wheelchair would only be used in the school environment. The residential setting could not accommodate the physical size of the powered wheelchair. This necessitated having the scanning interface independent of the wheelchair Interface Power Control Unit, thus leading to the "stand-alone" feature. In its place a passive type mobility base was being used to contain the postural support systems and the communication aspects of the interface would still be required in the setting.

3) The interface would have a user operable ON/OFF function to prevent accidental activation of the wheelchair while the user was attending to other activities.

4) The interface would provide visual feedback of the functions being scanned, the function being selected, and a power ON/OFF status indicator.

5) The interface would have a variable scan rate that could be adjusted to a rate consistent with the individual reaction and perception times.

6) The interface would have its directional functions priorized in the order of the most frequently used mobility directions and, when connected to a mobility device, would not scan the "PRINT" function. Each time the scan switch is closed, scanning proceeds through "LEFT", "RIGHT", "REVERSE" and ON/OFF functions. Should the "SCAN" switch be held closed beyond this point the scanner will recirculate.

Circuit Description

A block diagram of the scanning system is shown in Figure 5.

SCANNING INTERFACE

A two-switch six-channel scanning system was developed to provide four directional functions (FORWARD, LEFT, RIGHT, REVERSE), and ON/OFF or inhibit function and a PRINT function that can only be scanned when a communication aid is connected.

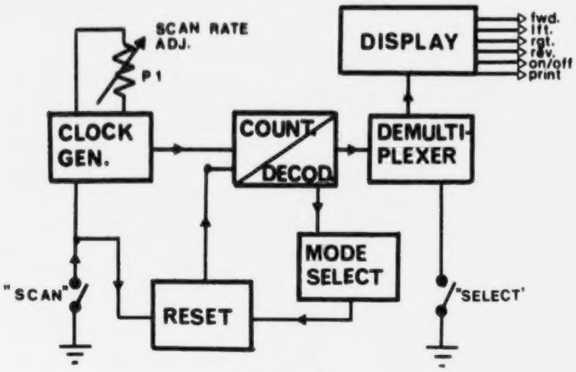

Figure 5

A Block Diagram of the Scanning Interface

The "SCAN" switch enables a clock generator which controls the scanning rate. The frequency of the generator is adjusted via P1 which produces a variable scan rate of 0.8 to 3.0 seconds per function.

The output of the clock generator increments a BCD counter whose outputs are decoded by a BCD to decimal decoder. The decoder generates an address which is presented to the demultiplexer.

The "SELECT" switch enables the appropriate one of six outputs only if the ON/OFF function is in the "ON" condition.

Figure 6

The Scanning Interface

The MODE SELECTOR automatically decodes the selection of the DRIVE or COMMUNICATION mode. If the interface is in the communication mode, the MODE SELECTOR enables the scanning of the PRINT function.

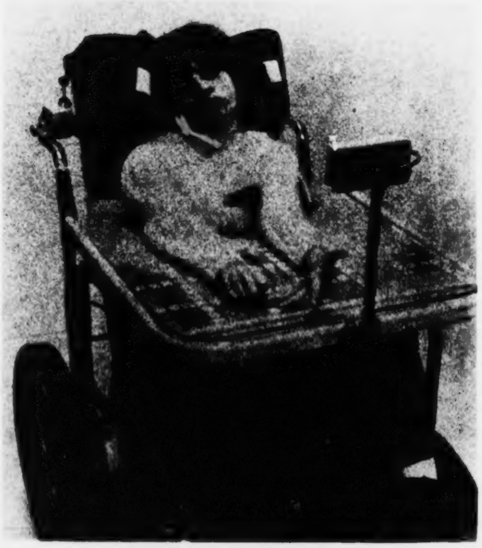

Figure 7

Scanning Interface Shown Operating The Powered Wheelchair

A visual display provides instantaneous feedback of the FUNCTION SCAN, FUNCTION ENABLE and ON/OFF mode.

The outputs of the Scanning Interface are applied to an Interface Power Control Unit^3 where the CMOS logic levels are translated into power signals for driving the wheelchair motors. When used with the Popstar* communication aid there is an associated switching box, again, to translate the CMOS levels.

The scanning interface illustrated in Figure 6 is housed in an OKW plastic case 4 3/4" x 2 1/2" x 1 1/2" (12 x 6.3 x 3.8 cm.).

The mobility and communication modes of operation are illustrated in Figures 7 and 8 respectively.

CONCLUSION

The scanning interface has provided access to independent mobility and communication for this cerebral palsied individual. Proficient use of the hardware system has been demonstrated and confirms the expectations consequent on the earlier software interface assessment.

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* Popstar - this communication aid provides an electro-mechanical finger that can be manouevered over the keyboard of conventional electric typewriter to access its characters. It also provides limited environmental control and attendant call features.

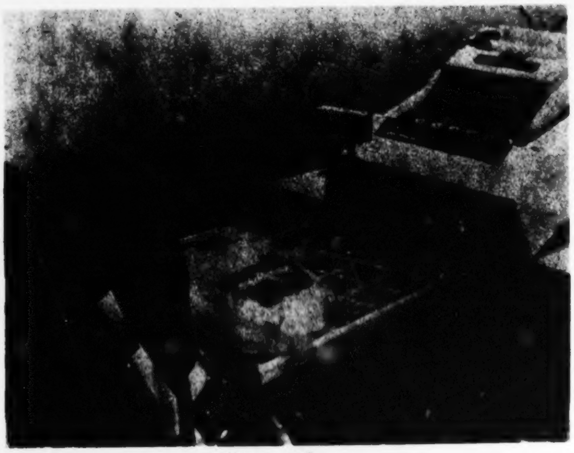

Figure 8

The Scanning Interface in a Typical Communication Application

ACKNOWLEDGEMENTS

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REFERENCES

1.) Edward Snell. "Capacitive Touchplate Controller for Powered Mobility in Severe Motor Disability". Proceedings of the Fourth Annual Conference on Rehabilitation Engineering, Washington, D.C., August 30- September 3, 1981, pp. 69-71.

2.) A. Basacchi, S. Naumann, and M. Milner. "Microprocessor Based Assessment of Controller Interfaces for Disabled Users". Proceedings of the Fourth Annual Conference on Rehabilitation Engineering, Washington, D.C., August 30-September 3, 1981, Washington D.C., USA.

3.) W. Literowich, G. Chau, S. Naumann, and M. Milner. "A multi-interface wheelchair controller". Proceedings of the International Conference on Rehabilitation Engineering, June 16-20, 1980, Toronto, Canada, pp. 120-122.

Address:

Rehabilitation Engineering Department
Ontario Crippled Children's Centre
350 Rumsey Road
Toronto, Ontario, Canada
M4G 1R8

THE IMAGES PROJECT
The application of high resolution, real-time, full-color graphics simulation to rehabilitation.

Larry, Leifer, Ph.D., Michael Zomlefer, Ph.D., William La, Ph.D.,
Machiel Van der Loos, Rehabilitation Research and Develoment Center
and Gregory L. Goodrich, Ph.D., Western Blind Rehabilitation Center,
Veterans Administration Medical Center, Palo Alto, California

ABSTRACT

Simulation technology has made important contributions to the aerospace industry by providing safe, cost-effective research environments. The IMAGES (Interactive Motion and Graphic Environment Simulation) Project will extend this technology into the rehabilitation field. Two primary research areas have been identified. One is the development and evaluation of wheelchair control systems. The second area of research is the design and evaluation of low vision aids and training procedures. Both areas will emphasize performance and preference measures.

INTRODUCTION

Simulation technology has proven to be a cost-effective means of training flight crews for both military and commercial applications. The value of this technology for the military has been documented in hearings before the Senate Subcommittee on Research and Development (2). Simulation has also become an important tool in product design (i.e., CAD/CAM). More recently, it has become an important, innovative tool in motion picture production.

Although these applications are diverse, simulation technology offers each a variety of essential advantages. First, simulation technology offers a safe research and training environment. Flight crews can be trained without risk of accident. Second, it is cost-effective. The need for expensive vehicles or flight equipment is eliminated which saves on fuel, equipment wear and other consumables. It is also cost-effective because many engineering designs can be tested, and compared, without the need to build expensive prototypes. Third, simulation allows training to occur in novel situations. Such situations can be created when needed by training or research schedules, thus avoiding costly delays or expensive travel to find the needed conditions. Fourth, simulation offers a near ideal training environment. Pilots and drivers can practice in a wide variety of conditions and their performance can be objectively assessed and replayed. And fifth, research is facilitated because the environment is controlled and replicable.

The IMAGES project will test the hypothesis that simulation technology can play a central role in rehabilitation. This will be accomplished by defining key equipment and training parameters which will lead to the development of relevant, user operated simulators for use in rehabilitation centers and/or the homes of the disabled. There are three key levels of implementation:

1. General purpose, high performance simulation (a research grade, powerful, complex simulator requiring highly skilled operators).
2. Task specific simulation (of clinical, diagnostic, treatment, or training environments requiring moderately skilled operators).
3. Personal simulation (develop simulators dedicated to a single user for task specific training and performance maintenance which can be user operated at his/her home).

BACKGROUND

Researchers at the Rehabilitation Research and Development Center (RR&D, Veterans Administration Medical Center, Palo Alto, California) had previously explored the feasibility of acquiring high resolution, real-time graphic capability. Limited capability simulation had already been shown to be an effective research tool (1,3,5). It was determined that while a high performance simulation capability was highly desirable, its cost was prohibitive. Currently there are only about 40 such systems in existence. These systems cost from 10 to 40 million dollars each and are primarily used in the military and aerospace industries.

In 1981 the Singer Link Corporation began negotiation of a donation of a high resolution, real-time digital image graphics sytem (DIGS) (4) to Stanford University. The negotiations were completed in late 1982 and plans were made for moving the DIGS to the Veterans Administration Medical Center in Palo Alto. The system, to be housed at the Western Blind Rehabilitation Center (WBRC, Veterans Administration Medical Center, Palo Alto, California) would be used by researchers from the RR&D Center and WBRC to explore the application of simulation technology to rehabilitation.

METHOD AND MATERIALS

The DIGS is characterized by a number of notable features including: 1) bright, high resolution color video display system capable of presenting daytime and nighttime scenes; 2) large screen display with optics for a virtual image at infinity; 3) interactive control of the "point-of-view" displayed; 4) dynamic modeling of vehicular motion; 5) comprehensive 3-dimensional modeling of the visual environment with perspective, hidden surface removeal, programmable illumination and animation of objects in the environment through joystick (and other) controllers.

The DIGS' utilizes a 1024 by 1024 pixel raster display with 24 bits/pixel for color saturation and intensity. From the view point the display is 40 degrees wide by 30 degrees high and is focused at infinity. The system is easily interfaced to a moving base simulator simulator to provide the user with a 3 degree of freedom (roll, pitch and yaw) sense of motion corresponding to the characteristics of the visual display.

Hypothesis - Externally Powered Mobility

An advanced general purpose vehicle simulator is needed to determine the specifications for clinical grade simulators. With "proven" specifications available, low cost (limited performance) simulators can be manufactured for a wide range of diagnostic and training applications (for example, to safely assess an individual's capacity to drive an automobile and to provide realistic driver training).

An interactive graphics system with real-time vehicle dynamics can be used to determine the key specifications for the next generation of electric powered wheelchairs. This is especially desirable as new technology and new design concepts (modularity, omni-directionality, intelligence, etc.) promise to make powered mobility accessible to more disabled individuals and to make that mobility more effective.

Simulation, both in advanced research and in the clinical application environment, will allow for simultaneous measurement of user performance and user preference. Performance measures include a digitized record (time line) relevant to the required task, which can provide a measure of performance (e.g. RMG error) and subsequent measures can be quatitatively compared to examine learning and other experience factors. Other measures include integral error, control reversals, performance delay, and decision making records. This data can then be compiled to provide an optimal control model of the operator based on fitting analytic functions to observed data (e.g., comparisons of the models obtained given specific display and control variables). The user's preference can be related to the above data with either control characteristics set by the researcher or with control characteristics set by the user.

Hypothesis - Low Vision Mobility

An advanced general purpose vision simulator can be used to visualize a variety fo pathologies, including: macular degeneration, retinitis pigmentosa, cataract, diabetic retinopathy, and glaucoma. When these perceptual disabilities have been visualized, it will be possible for the non impaired individual to see what the patient is experiencing. A professional and public education film can be produced for research and training purposes.

Simulation can also be used to provide performance measures which allow quantification of relevant variables including; the visual cues that enhance or restrict mobility, the interaction of lighting conditions with environmental characteristics which ehance or restrict mobility, the effectiveness of visual training upon performance in mobility, and the effects of low vision aids upon mobility performance. User preference for environmental characteristics, lighting, training, and aids can be related to the above measures and to the user's visual characteristics to provide predictive information relevant to the user. Data from a group of appropriate subjects can be used to develop improved low vision aid specifications. With "proven" specifications available it may become possible to develop low cost (limited performance) simulators for diagnostic and training applications including; defining and assessing mobility performance, providing eccentric viewing training and providing driver assessment and training.

An interactive system with real-time dynamics can be used to determine key specifications for the next generation of low vision mobility and orientation aids. This is especially desirable as new technology and new design concepts (modularity, intelligence, speech input/output, tactile displays, etc.) promise to make more low vision individuals effective travelers in a greater variety of environmental conditions.

FIRST YEAR OBJECTIVES

The IMAGES project is a multi-year endeavor to promote rehabilitation research through the application of simulation technology. While long range goals will be dependent upon earlier findings the initial applications of the DIGS can be defined. These include:

1. June 1983, installation of the system within the Western Blind Rehabilitation Center, VA Medical Center, Palo Alto.
2. Verification of function of the installed system with an existing data base and perform an acceptance demonstration test at the VA. The acceptance test is scheduled for September 1983.
3. Initial mobility simulation research:
   a. Establish a mobility simulation research program advisory group.
   b. Perform a study of wheelchair simulator vision and control requirments and prepare simulator and data base specifications for the first mobility study.
   c. Perform a pilot study related to the desirability and feasibility of specifications contained in the anticipated VA request for proposals (RFP) related to the development and manufacture of a module wheelchair power base.
   d. Based on cue analysis results from the wheelchair pilot study, develop preliminary specifications for a low

cost wheelchair driver training simulator that can be used widely in other VA facilities.

4. Initial low vision simulation research:
    a. Establish a low vision simulation research program advisory group. This group has been established and held its first meeting on January 21, 1983.
    b. Perform a study of vision and control requirments in low vision research and prepare simulator and data base specifications for the first study of visual pathology.
    c. Perform a pilot study related to critical cue definition for successful navigation within a well controlled visual environment. Demonstrate the results with a simulation training/education film.
    d. Based on cue analysis results from the low vision pilot study develop preliminary specifications for a low cost low vision mobility training and assessment simulator that can be used widely in other VA facilities.
5. Define alternate studies in rehabilitation science and technolgoy that may best be performed with the DIGS system. Discussions with a variety of investigators in rehabilitation and related disciplines has already begun.
6. Write and edit a technical report for intramural VA purposes. The report will include test protocols, test results, simulator specifications and vendor data needed to maintain the DIGS system for further research and development.

DISCUSSION

The donation of the DIGS represents a milestone in rehabilitation. It is the first opportunity to apply state-of-the-art technology to rehabilitation. In many areas including the aerospace industry, computer-aided design, computer- aided manufacture and motion pictures simulation technology has proven itself a safe, cost-effective tool. The IMAGES project will test the hypothesis that simulation technology can play a central role in rehabilitation.

Through the generosity of the Singer Link Corporation, work with the DIGS was able to commence prior to its delivery. This work included the development of the initial data base, which used a local Palo Alto shopping center as its model. It was a pleasant surprise to both wheelchair and low vision researchers that the needs of both could be initially met by a single data base. This saved considerable time for both research projects. Development of the data base utilized both architectural drawings and photographs of the shopping center. An alternative, more efficient means of creating data bases is also being developed using an Apple II computer. Work is also progressing on the Low Vision Simulation Education/Training film and on a brief documentation video tape of the IMAGES project.

It is anticipated that the IMAGES project will mark a milestone in wheelchair and low vision research and lay the foundation for research in additional rehabilitation fields. Already the relevance of auditory simulation to low vision research has been discussed by us and our low vision advisory committee. Such simulation could have benefit to the hearing impaired and will continue to be explored. In short, the IMAGES project already combines the needs of the physically and visually impaired and it could become a unifying force within rehabilitation.

ACKNOWLEDGEMENTS

The IMAGES Project is made possible by the donation of the DIGS by the Link Division, Singer Corporation, Sunnyvale, California to Stanford University and is supported by funding from the Rehabilitation Research and Development Service, Veterans Administration, Washington, D.C.

REFERENCES

1. Jaffe, D., et al., Smart Wheelchair, Proceedings of the 4th Annual Conference on Rehabilitation Engineering, Washington, D.C., 91-93, 1981.

2. Flight Simulators, Proceedings of the Hearing before the Subcommittee on Research and Development of the Committee on Armed Services, United States Senate, Washington, D.C., May 13, 1976.

3. Shung, J.B., et al., Dynamic Modeling and Analysis of a Wheelchair, submitted to ASME Transactions on Biomechanical Engineering, 1982.

4. Singer Link, DIG Simulator, Technical Manual, Link Division, Singer Corporation, Sunnyvale, California, 1976.

5. Zarrugh, M.Y., Miller, J.D., and Koopman, R., Stability Considerations of Adaptive Steering Systems for the Disabled Driver, Proceedings of the 5th Annual Conference on Rehabilitation Engineering, Houston, Texas, 105-6, 1982.

Authors address:

Larry Leifer, Ph.D., Director, Rehabilitation Research and Development Center - 153, Veterans Administration Medical Center, 3801 Miranda Avenue, Palo Alto, California 94304.

EVALUATION OF A SPEAKER-DEPENDENT VOICE RECOGNITION UNIT AS AN INPUT DEVICE FOR CONTROL OF A ROBOTIC ARM

Roger Wicke, K.G. Engelhardt, Roger Awad, Larry Leifer, Machiel Van der Loos
Veterans Administration Medical Center,
Palo Alto, California

ABSTRACT

A Voterm (Interstate Electronics) speech recognition unit was evaluated using five non-disabled and five disabled (quadriplegic) users, prior to their using the unit as an input device for controlling a robotic arm. Users were trained on the unit with a vocabulary of 25 words; then the unit's recognition accuracy was tested during the utterance of each of the 25 words. Most of the users were requested to speak in a normal voice during the testing; however, one non-disabled and one disabled user were asked to systematically alter their voice quality during the recognition tests in order to determine to what extent recognition was degraded.

In the normal voice tests, certain words created problems in either the training procedure or recognition. Often, this was due to insufficient amplitude. Quadriplegics often have partial paralysis of the diaphragm and/or larynx and cannot speak as loudly as a normal person.

Once training was completed, most of the users achieved recognition rates of 100%. However, when the same vocabulary was used in the context of controlling the robotic arm, frequent recognition errors occurred. Possible reasons are discussed.

INTRODUCTION

For the severely disabled, voice input is one of the most promising means of controlling various assistive devices. Voice recognition systems have been used successfully to control powered wheelchairs and environmental control systems (1). For people who have high-level spinal injuries or who are suffering from advanced degenerative neurological diseases, speech may be one of the few remaining means of communicating.

In order for a disabled person to use a speech recognition system successfully, any speech abnormalities they may have must not interfere with the recognition capabilities of the system. Many quadriplegics and patients with degenerative neurological diseases have partial paralysis of the larynx and muscles of respiration, which may diminish phonation quality and voice amplitude (2). These possibilities must be considered when evaluating the appropriateness of speech as an input mode.

A speech recognition system for use in these circumstances should incorporate features which have demonstrated maximum recognition of command words in the context of device control. The use of isolated individual commands (in contrast to continuous speech), speaker-dependent template-matching algorithms, limited vocabulary size, and dynamic time warping have all been shown to allow the best recognition rates (3). These characteristics are compatible with the task of controlling a device, and we have chosen a recognition system (Voterm) which has all of these features.

METHODS

We have been using a Voterm user-dependent speech recognition unit as the primary input device to allow control of a robotic arm. Various arm motions are initiated by specific spoken commands from a vocabulary of 57 natural language commands. For safety and ease of use, accurate recognition without frequent confusion of commands is desirable. Several factors interact to influence the quality of recognition: the consistency with which each user repeats command words in training and in use, and the inherent capabilities of the device itself. We have evaluated the speech recognition device with several goals in mind: (1) to determine the limitations of the device; (2) to improve the choice of vocabulary words in order to minimize confusion errors; and (3) to determine whether and how the user can be trained to improve voice consistency.

The Voterm requires a user to repeatedly utter each vocabulary word so that a template can be formed for each word. Then, when an utterance is spoken, the unit compares the current utterance with all of the stored templates; the template which matches most closely corresponds to the vocabulary word which is recognized. Of the several numbers which are generated by the Voterm after each recognition, the match index will be used in this paper to quantify the results of our tests. This match index is a number which represents the degree to which an utterance matches the template of the vocabulary word which is recognized. A perfect match corresponds to a match index of 128, and any variation in the utterance from the training template will result in a lesser value.

RESULTS

Systematic voice variation tests

One non-disabled and one disabled subject were instructed to say ten of the command vocabulary words with the following ten voice qualities: normal voice, loud, moderately quiet, fast, moderately slow, with high pitch, low pitch, rising inflection, falling inflection, and with a raspy voice. The disabled subject was able to perform only the normal, high-pitched, and moderately quiet variations; the others were too difficult. All utterances were tape recorded and then played back into the input terminal of the

Voterm. The Voterm was trained by playing back the normal utterances for six repetitions. Then, the utterances using altered voice quality were input in order to test the recognition performance.

Figure 1 shows the match indices for each word (non-disabled subject RW only) with voice characteristics as the parameter. Variations in speed (fast and slow) affected recognition the least, which is reasonable, since the Voterm incorporates dynamic time warping into its recognition algorithm. Raspiness degraded recognition performance the most. Nevertheless, for this limited vocabulary of ten words, no confusion errors ever occurred. Figure 2 shows the averaged match indices for all ten words in each category. (Subject PR was the quadriplegic speaker.)

Normal voice tests

Four quadriplegic and five non-disabled subjects were tested using a vocabulary of 25 words. All subjects were instructed to speak with a normal voice. The 25 words were a subset of the larger 57-word vocabulary used with the robotic arm. Each subject trained the Voterm with six repetitions of the 25-word vocabulary. Then the list of 25 words was repeated twice more to test the recognition performance. The most frequent problem in this test occurred because of rejected utterances during the training procedure. This happened much more often for the quadriplegics than for the non-disabled speakers. This was due to the fact that certain words lack high amplitude phonemes, and can be a problem for people who have weak voices. These words were eliminated from the list if the utterances were repeatedly rejected. However, for all words which were successfully trained, no confusion errors ever occurred for any of the subjects.

Vocabulary recognition during use with robotic arm

After the subjects completed these preliminary voice tests, they trained with the Voterm using the full 57-word vocabulary required in order to use the robotic arm. During the actual use of the robotic arm, all instances of recognition confusions and other errors were tabulated. Recognition errors were much more frequent than during the previous tests, but there was no discernible difference in recognition performance between disabled and non-disabled speakers. There are a number of possibilities which may account for this phenomenon. The most trivial possibility is that the full 57-word vocabulary would have more likelihood of confusion errors in general. However, the fact that certain users have much greater success in avoiding such errors suggests that an important variable is the consistency of utterances. People who are unfamiliar with the robotic arm and its engineering and function may be more likely to alter their voice quality as a result of anger, fear, stress, or frustration in response to malfunctions. Such changes may be manifested either as a shift of the vowel formants or as a change in articulation.

In an attempt to improve utterance consistency, one subject retrained the vocabulary, making a conscious effort to say each word clearly, with perfect enunciation, and with a robot-like quality. Recognition performance during subsequent use of the robotic arm improved dramatically.

FUTURE STUDIES AND RECOMMENDATIONS

To reduce the frequency of recognition errors during use with the robotic arm, certain commonly confused vocabulary words will be changed to other synonyms. Also, users may be able to intentionally alter their manner of speaking to increase consistency, although it is not known whether they can comfortably achieve this. Changes in vowel formants and articulation patterns of users will be studied while they are controlling the robotic arm.

We are in the process of testing other speech recognition systems in order to evaluate their suitability for use by disabled people in controlling assistive devices.

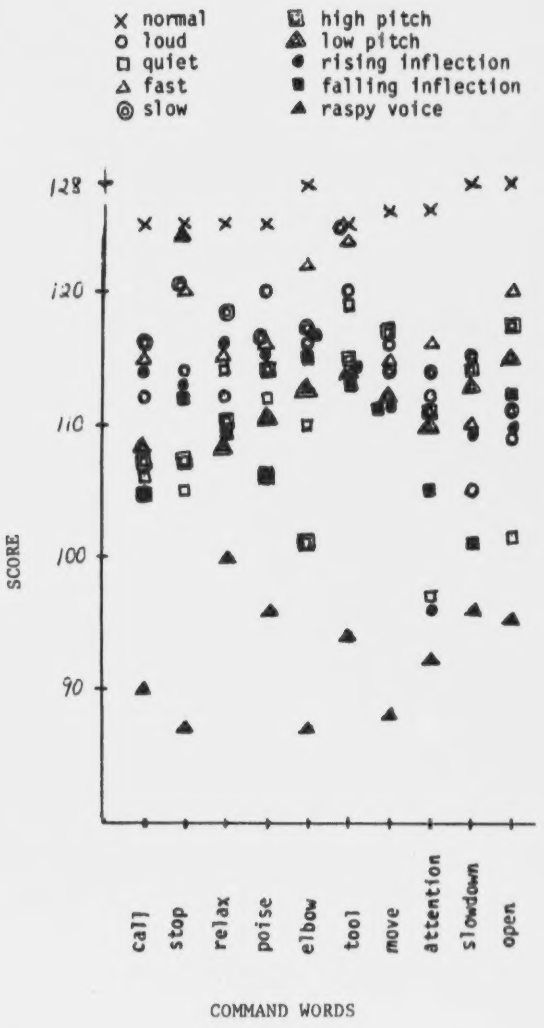
REFERENCES

1. Youdin, M. et al. A voice controlled powered wheelchair and environmental control system for the severely disabled. Medical Progress through Technology, 7, 139-143 (1980).

2. Moore, G.P. Voice disorders organically based. In Handbook of Speech Pathology and Audiology, Appleton Century Crofts, New York, c1971, pp. 535-569.

3. Flanagan, J.L. Talking with computers: synthesis and recognition of speech by machines. IEEE Transactions on Biomedical Engineering, BME-29,4 (1982).

Figure 1.



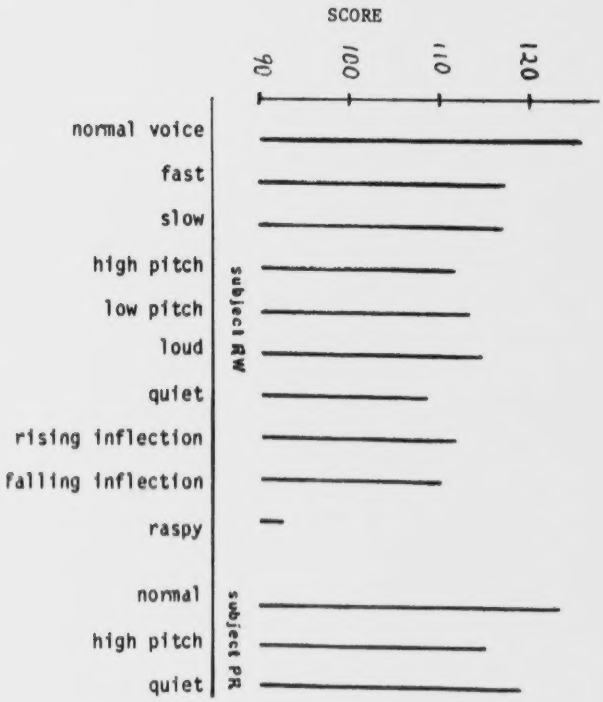


Figure 2.

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Rehabilitation Research and Development Service
Veterans Administration Medical Center
Palo Alto, California

Dorothy Huntington, Ph.D.
Experimental Phonologist
Speech Science Lab, Stanford Medical Center

Author's address:

Roger Wicke, Ph.D.
Rehabilitation Research and Development Service (153)
Veterans Administration Medical Center
3801 Miranda Avenue
Palo Alto, California 94304

DESIGN OF A SIX-AXIS INPUT DEVICE FOR A ROBOTIC MANIPULATION AID

Van der Loos, Hendrik F. Machiel

Palo Alto Veterans Administration Rehabilitation R&D Center

ABSTRACT

The applicability of robotic manipulation aids for the physically handicapped depends largely on the device used as the man/machine interface. Commanding a system to perform a task is possible through keyboards or by voice, but guiding the motion of a mechanical arm requires an analogic input device, such as a joystick, for effective, real-time control. The design of a six degree-of-freedom joystick is discussed; a prototype implementation is described; and its role as an effective assistive device is postulated.

INTRODUCTION

The impairment of motor function as a result of, for example, spinal cord injury leads to an individual's handicap in self-care and vocational endeavors. One recent application of robotics involves the restoration of the patient's capability to manipulate objects in his personal space. Through modalities, such as voice, joystick input, and head motion, a robotic arm can be guided through the logic and through the trajectories to accomplish complex manipulation tasks for its user. The generic term 'joystick' refers to any input device of a specified number of degrees of freedom that transduces motion and/or force to electrical signals.

In the use of a joystick, the operator is called upon to perform a mapping of the joystick inputs to the motions induced in the controlled device. In the case of a 2-axis electric wheelchair joystick, this is a simple mapping task; in the case of a six degree-of-freedom (6-d.o.f.) robot, a joystick must be designed to reduce the mapping to instrumented 'pointing' in the desired direction of motion of the gripper. The latter was the primary goal of the process leading to a 6-d.o.f. joystick design applicable to rehabilitative robotics in particular.

Interfaced to a voice-controlled robotic manipulator, the joystick permits analog control of the mechanical arm's motions by a user having limited manual dexterity, range of motion, and force.

BACKGROUND

Industrial robotics concentrates on developing fully automated alternatives to human function; telemanipulation research endeavors to produce a perfect mechanical extension of man for the handling of materials where he himself can not go. In between these 2 fields lies Interactive Robotics. The goal of this field is to combine direct human control of a mechanical arm with automation, by an on-board computer, of low-level operations such as obstacle avoidance, object centering and grasping, peg-in-hole insertions, and line- and plane-following. The concept of distributed decision-making involves human switching of operation modes through a symbolic information channel (keyboard or voice), and human analogic control of real-time processes through a joystick configuration (3,8).

In the field of rehabilitative robotics, R&D emphasis has been placed on endowing the manipulator system with pre-programmed features (9), restricting human input to a minimum. The search for a lowest-common-denominator input device for use by a large proportion of consumers with a range of disabilities is desirable for implementation standardization. On the other hand, devices designed on an individual basis and exploiting the remaining motor and expression functions could offer the user a much richer interaction. An example is the 5-d.o.f. hydraulic mouthstick with grip force feedback developed by Torfason (12). Full-range and dexterous head motion is required, thus usable by C-4 and below quadriplegics. The device directly controls the actuators of a hydraulic telemanipulator. Hand-operated joysticks of more than 3 axes are not common in industry, and only very few 'full-access', i.e. 6-d.o.f., controllers exist even in R&D environments. Lower-level quadriplegics, arthritics, and those with birth defects may have residual use of one or both upper limbs. Limited manipulation ability can be rendered useful through special devices: velcro strips for wheelchair joystick attachment, strap-on spoons, etc. Using residual ability for the control of a 6-d.o.f. joystick is deemed possible through extrapolation of proven industrial joystick design concepts and innovative control strategies.

Preference and performance tests have been conducted in tracking and positioning tasks. Through these and the last century's evolution of the design of control devices, certain concepts have emerged. The most basic is the preference of the user to be part of a linear control system (4). Non-linearities in the linkages or behavior of a system, such as backlash, stiction, delay in response, and saturation of the control input are diagnosed as being undesirable. Though actual performance may not always be diminished (10), increased concentration levels and frustration can be psychological deterrents to a system's effectiveness.

For a linear system, the magnitude of the gain factor between the input device signal and the observed effect is not strongly related to performance. Indeed, in one study it was shown that over a gain factor range of 100, the performance varied by two orders of magnitude less (11). In this study and elsewhere (13), it was noted that there did appear to be a local optimum corresponding to a specific controller gain. This observation points up the need for an optimization phase for any controller implementation if maximum performance is desired.

The second concept involves the role of proprioceptive feedback. Best performance results have been obtained for spring-return displacement sticks and isometric joysticks (7). The first category has an advantage in jolting controller environments, such as electric wheelchairs, where the hand's accelerations cause disturbance forces to be imparted to the control stick: the added position cue of displacement minimizes the disturbance effect (5). The second use for proprioceptive feedback is in distinguishing one axis of control from another. A controller with a center-detente permits full linear behavior throughout the non-zero control space, while cuing the operator when the zero-position in any direction is attained. For an electric wheelchair, this provision allows for forward motion without controller-induced side-to-side drift.

The third concept involves directional stereotypes. As users of appliances, vehicles, and robots, we expect a forward push on a control stick to induce forward motion on the controlled device. Studies have shown that deviations from expected relationships are very difficult to incorporate permanently (6).

The above concepts of linearity, proprioception, and directional expectations have been used as the basis for the design of a 6-d.o.f. manual joystick for a computer-controlled mechanical arm.

METHODS AND MATERIALS

The context of the joystick project is the Stanford University and PAVAMC RR&D Center Robotic Aid for the Handicapped (5). Based on an industrial manipulator, the Unimation PUMA-250, augmented by a Z-80-based host processor, and voice recognition and synthesis modules, and run on innovative control software (6), the system allows easy incorporation of additional I/O devices, such as displays and joysticks.

A prototype 6-d.o.f. joystick, VIDOF (fig. 1), employs 2 groups of 3 inputs, separated into major and minor axes (fig. 2). The 3 major inputs are managed by a wrist-centered handgrip, controlling the translations of the gripper of the robot along the 3 cartesian axes (x,y,z). The minor inputs are managed by the thumb and forefinger through a finger-stick mounted on the handgrip platform. These 3 inputs control orientation (pitch: rx, roll: ry, yaw: rz).

Each control axis is of the center-detente, displacement type, with the ranges of motion adapted to human anatomy. Force gain factors are adjustable.

Computer software to convert the 6 inputs to robot arm velocities permits the study of 1) effects of controller gains and saturation, i.e. maximum attainable speed, 2) the use of filters to remove or diminish the effects of spasms and other non-linearities induced by the user's disabilities, and 3) the optimum topological mapping of joystick inputs to robot control directions.

RESULTS AND DISCUSSION

A prototype has been built (VIDOF), implemented, and has undergone a preliminary phase of parameter adjustment for able-bodied users. Qualitative feeback from users indicates that the device requires a learning stage before confidence is attained. The joystick allows complex, high-speed maneuvers with the arm: similar to driving a race car, this is a scary adventure for the neophyte.

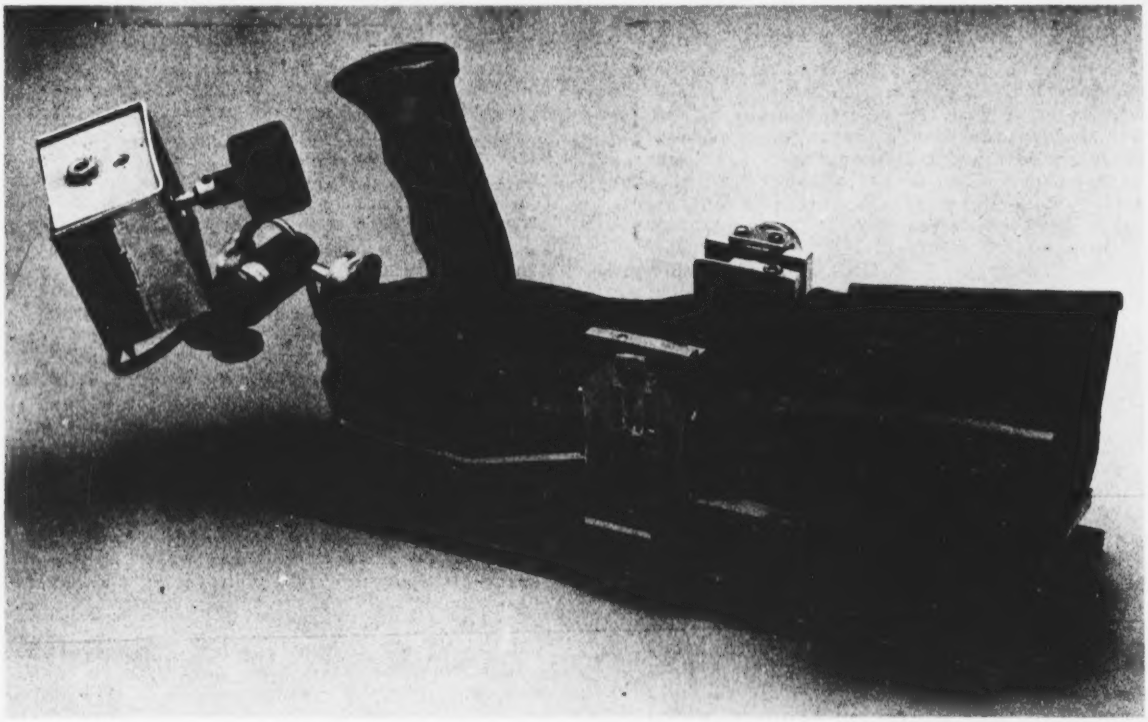

Fig. 1. VIDOF 6-d.o.f. Joystick Prototype.

The implementation is in conjunction with the software package designed to allow voice control of the arm. The symbolic input, though also available for voice-piloting ("left", "forward", "turn", etc.) is primarily used to complement the analogic joystick input: mode changes and coordinate system modifications are done by voice commands.

As the development of VIDOF is only in its initial stages, a number of studies and tests are projected. The most salient is the study of characteristics and features required for optimal use by both the able-bodied and those with limited arm amd hand capabilities. Spring rates, center detente levels, ranges of motion, software filter types and parameters, and mapping conventions are physical quantities targeted for observation.

CONCLUSION

The development of analogic input devices for telemanipulator and robot systems is becoming feasible through the same advances in electronics that made robotics itself possible. The exotic field of rehabilitative robotics requires, by definition, energy to be spent on characterizing disabilities and utilizing remaining strengths. In addition to being a powerful environment for the design of assistive devices for the handicapped, this field can provide strategies and technologies for the development of multi-axis input devices in robot and telemanipulator stations in general. The joystick described here is an attempt to introduce a versatile device for a range of robotic applications.

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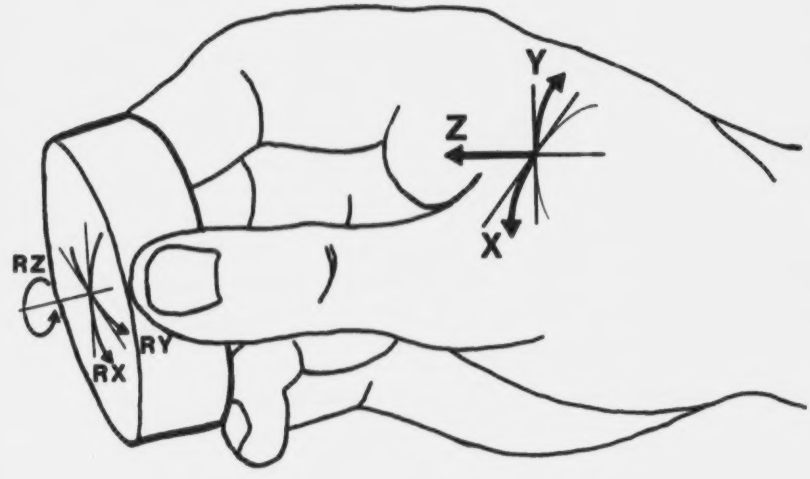

Fig. 2. Control Allocation of the Six Joystick Inputs.

REFERENCES

1) G.T. Black, Flying Qualities Design Requirements for Sidestick Controllers. Wright-Patterson AFB Rept. No. AFFDL-TR-79-3126, Oct., 79.

2) C.W. Buckley, L.J. Leifer, Fast Interactive Control of a Manipulator for the Severely Disabled. Proc. of the ACC, Arlington, VA, June, 82.

3) W.R. Ferrell, T.B. Sheridan, Supervisory Control of Remote Manipulation, IEEE Spectrum, vol. 4, Oct., 67, pp. 81-88.

4) D. Graham, Research on the Effect of Non-Linearities on Tracking Performance. Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio, July, 67.

5) L.J. Leifer, Rehabilitative Robotics, the Stanford Robotic Aid. WESCON '81, San Francisco, CA, Sept. 15-18, 81.

6) N.E. Loveless, Direction of Motion Stereotypes: A Review. Ergonomics, 1962, 5(2), pp. 357-383.

7) M.H. Mehr, Manual Digital Positioning in 2 Axes; A Comparison of Joystick and Trackball Controls. 16th Annual Meeting of the Human Factors Society, Oct., 72.

8) J.L. Nevins, D.E. Whitney, Information and Control Issues of Adaptable, Programmable Assembly Systems for Manufacturing and Teleoperator Applications. Mechanism and Machine Theory, 1977, vol. 12, pp. 27-43.

9) W. Schneider, G. Schmeisser, W. Seamone, Computer-Aided Robotic Arm/Worktable System for the High Level Quadriplegic, IEEE Computer, January, 1981, pp. 41-47.

10) G.P. Starr, Comparison of Control Modes for Time-Delayed Robot Remote Manipulation. Ph.D. Thesis, Department of Mechanical Engineering, Stanford University, 1978.

11) C.L. Tipton, H.P. Birmingham, Influence of Control Gain in a 1st-Order Man-Machine Control System. Human Factors, 1959,1, pp. 69-71.

12) L.E. Torfason, F.C. Risteen, A Single Joystick Hydraulic Control System with Six Independent Simultaneous Velocity Proportional Degrees of Freedom. ASME publ. 70-MECH-54, 1970.

13) T.C. Way, Studies in Manual Target Designation: Isometric Control, Report D162-1025801, Boeing Co., Seattle, July, 1970.

ADDRESS

VA RR&D Center (MS 153)
3801 Miranda Avenue
Palo Alto, CA 94304.

Ultrasonic Head Control Unit

David L. Jaffe
Ronald F. Gaines M.D.
Palo Alto VA Medical Center
Rehabilitation Research and Development Center

ABSTRACT

In this paper, a unique man/machine interface will be presented. Remote, real-time, non-contact sensing of the user's head postion is accomplished using Polaroid Ultrasonic Sensors. The transduced head position signals can be used in the control of a wide variety of rehabilitation devices including head pointing communication and environmental control systems, real-time robotic arm and electric wheelchair control, head controlled video games, and robotic obstacle location.

NEED

An important part of any piece of electronic or mechanical system is its interface with the human user. In devices for able-bodied people, these interfaces are well worked out. They include knobs on radios, steering wheels, gear shift levers, and brake pedals on cars, keyboards on typewriters, dials on telephones, and push-buttons on electronic teller machines. However, individuals with disabilities, especially quadriplegics, may not be able to use these interfaces. The challenge of the rehabilitation community is to develop, evaluate, and bring to market interfaces that can be used.

The ideal interface for high level quadriplegics would include the following features.

1. It should be cosmetically appealing and socially acceptable to both the user and the individuals around him/her. An interface that performed its sensing at a distance, without mechanical contact, would be particularly appealing. The user should not feel 'wired-up' or 'robotized'.

2. The interface should not overload existing sensory channels. For example, an interface which requires constant user visual attention would be undesirable.

3. A successful interface should be adaptable to many users, accommodate their special needs, and be comfortable to operate for long periods.

4. An interface's control scheme should be intuitive, thus contributing to a short training period.

5. The ideal interface should be flexible in its output configurations in order to drive a variety of devices. Analog, digital, switch closure, and matrix outputs should be supported.

6. The control output data rate should be fast enough to control devices in real-time.

7. The interface should not pose any sanitation, maintenance, or medical problems for the user.

8. The interface should be of reasonable cost, and easy to obtain or replicate by other rehabilitation researchers.

PROBLEM

Table 1 compares several common man/machine interfaces. Each has some advantages over the others in a particular application or for a particular user. However, none meets all the criteria of the ideal interface as given above.

SOLUTION

An Ultrasonic Head Control Unit has been developed at Rehabilitation Research and Development Center. Its features are listed below.

1. Polaroid Ultrasonic sensors transduce the user's head position in the plane formed by the head and the two sensors. The ranging is done at a distance, without mechanical contact with the user, and at a sampling rate limited only by the speed of sound.

2. The interface information proportionally relates the user's head tilt position from the vertical. Two degrees of deflection are measured; the forward/backward component and the left/right component.

3. The unit can be considered a 'black box' which transduces head tilt positions in a manner similar to a joystick which produces voltages proportional to its position. In each case the outputs are used in control of devices to which it is attached.

4. In an effort to make duplication of the Head Control Unit easy, commercially available STD bus computer boards are used in this unit. Only the Polaroid sensor controller board is custom. Its construction is described in a recent issue of Robotics Age Magazine. The software runs from non-volatile memory and is available upon request.

5. The outputs of the interface can be configured by the user or researcher. Serial ASCII information can be sent from the Ultrasonic Head Control Unit to computer devices which accept this type of communication. The range and offset of the analog outputs can be adjusted to suit the requirements of other devices. Lastly, the user's head position can be mapped onto an X-Y matrix. The output of this mode is row/column information which would be useful, for example, in the control of communication boards.

USES

Some possible uses of the Ultrasonic Head Control Unit are given below.

1. Used in conjunction with an electronic language board, the interface could map the user's head position onto its text message space.

2. A portable Ultrasonic Head control interface could translate head motion into navigation instructions for a mobility device. Its use in the Smart Wheelchair has already been demonstrated. Other possibilities include the control of external mobility such as a robot servant.

3. Another real-time application is the control of a robotic arm. The user's head position could be used to maneuver the robotic hand while voice command could control the remaining joints.

4. In an environmental control situation, a system could map the user's head postion onto a CRT screen. By moving the head, a user could electronically point to displayed functions to be activated as demonstrated at last year's conference.

5. To provide video recreation, a head position controlled Pacman game could be implemented.

6. By aiming the sensors at the user's shoulders, a range of motion device could be developed. If such a device was used in conjunction with a game, the user could enjoy recreation while exercising normally under-used muscles. Simultaneously, the interface could be electronically recording the range of shoulder motion and the number of times a given excursion was produced. A mechanical shoulder control interface was shown at last year's conference.

CONCLUSION

The Ultrasonic Head Control Unit provides the user with a new means of communicating with devices he/she wishes to control. The remote sensing and high rate of data acquisition features are positive factors in making this unit a social and technological success.

ACKNOWLEDGEMENT

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David L. Jaffe
Palo Alto Veterans Administration Medical Center
Rehabilitation Research and Development Center
3801 Miranda Mail Stop 153
Palo Alto, CA 94304

Table 1 - Man/Machine Interface Comparison

Device	Mechanical Contact Required	Calibration or Training Required	Outputs	Cost	Activation Abilities Required	Maximum Data Rate
Keyboard	YES	NO	Multiple Switch Closure	$$	Arm and Finger Movement	5/Sec
Joystick	YES	NO	Switch Closures or Analog	$$	Arm Movement	30/Sec
Chin Controlled Joystick	YES	NO	Switch Closures or Analog	$$	Head Movement	15/Sec
Voice Recognition	NO	YES	Electronic Switch Closures	$$$	Speech	1/3Sec
Pneumatic Switch	YES	NO	Switch Closure	$	Any Body Movement	1/Sec
Touch-Switch	YES	NO	Switch Closure	$$	Any Body Movement	1/Sec
Mouth Stick	YES	NO	Activation at a Distance	$	Head Movement Sight	1/Sec
Optical Head Pointer	YES	SOME	Matrix	$$$	Head Movement Sight	3/Sec
Arm Slot Switch	YES	NO	Multiple Switch Closure	$$	Arm Movement	1/Sec
Eye-Tracking	NO	YES	Matrix	$$$	Eye Motion Sight	1/Sec
Puff-Sip Control	YES	NO	Switch Closure or Analog	$	Pressure Generation	2/Sec to 30/Sec (Analog)
Ultrasonic Head Control	NO	SOME	Analog, Digital, Matrix	$$$	Head Movement Sight	30/Sec

Legend: $ = $1 - $10 $$ = $10 - $100 $$$ = $100 - $1000

A NEW APPROACH TO A PROSTHETIC CONTROL BY A BINARY CODED EMG SIGNAL

Amit Ailon, Ph.D.
Department of Biomedical Engineering
Rensselaer Polytechnic Institute

ABSTRACT

In this paper we shall present a method which gives the disabled the ability to control a prosthetic arm or another electromechanical device, e.g., a wheelchair, by one anatomically chosen site where surface electrodes measure an EMG signal. Man-interactive computer simulation was successfully used in our study of this method.

INTRODUCTION

A man-prosthetic/orthotic arm is a man-machine system. Interface strategies for communication between the man and the machine are the core of the problem of efficiently controlling the mechanical system attached to the patient's body (1). As the system becomes more complicated, the operator's mental effort in controlling the system is increased considerably. This is because the control of a multidegrees of freedom device with a complex movement pattern requires input signals of high information content.

The EMG signal available to control an artificial limb comes from residual muscles. In general, previously developed prostheses for multifunctional control of upper limbs fall into one of the following categories: (a) a control system based on a synergy pattern recognition concept for multiple-axis prosthetic applications (2), and (b) multi-functional control of artificial upper extremities by identifying its time series model (3, 4). In the first category, information is gathered from multiple muscle sites by simple processing, while in the second category, more information is gathered by a more complex processing from only one site. Evaluation of the two procedures has so far been quite limited (5).

The purpose of this paper is to suggest a new approach to control a multiple degrees of freedom prosthetic arm by an EMG signal from a single source.

RATIONAL AND CONTROL PROCEDURE IMPLEMENTATION

In terms of control theory, the organization of the human body's system of motion implies the concepts of levels and hierarchy (6). Let's define such a hierarchical control system, organized on three levels. The first level is the decision-oriented level (the operator); the second level is the algorithmic level (the minicomputer or the microprocessor); and the third level is the dynamic level (including the actuators and the mechanical system, such as the prosthetic arm). The objective of this control system is to realize the idea of separation of control tasks by a separation into two distinct types of activities: decision-making and implementation of the decisions (6).

In terms of the previously defined hierarchical system, any decision which the operator makes is translated into an appropriate command transfer through an EMG signal to the minicomputer (microprocessor). On the algorithmic level, the computer reads the operator's command together with the current angular motor positions and calculates the angular motion rates of the driving motors required to produce the specific movement. In this control system, the operator's task is only to adequately determine the entire algorithm rather than controlling piecemeal all the separate parts of the motion.

In developing an appropriate algorithm for our method, we referred to Whitney's work (7,8). He suggested some capabilities that could be provided if resolved motion rate control were available. His suggestions are based on the idea that it is more natural to drive a hand motion along a directly relevant direction than through the tedious task of controlling several joint-motors simultaneously.

The operator communicates with the minicomputer through a single EMG signal. This signal is a non-stationary stochastic process. It must be remembered that any functional mathematical model of myoelectric activity is extremely complicated for any specific application (9,10). However, two important points about this situation are clear. First, the contraction of any muscle is associated with increasing the amplitude of the myoelectric signal above a certain threshold, and second, one can easily contract a voluntary muscle during a shorter interval of time than a given interval of time; likewise, one can easily contract a voluntary muscle during a longer interval of time than a given interval of time. For example, if we define an interval of time as one second in length, one can easily contract a voluntary muscle along some interval of time with the only limitation being that this interval is shorter than one second, or one can easily contract a voluntary muscle along an interval of time with the only limitation being that this interval is longer than one second.

This "either-or" possibility leads us to the idea of an EMG processing strategy using a certain kind of coding. To be more exact, by using an appropriate strategy and processing, the EMG signal can be encoded to a binary code. In Fig. 1 the input to the processor is a sequence of EMG signals coming from a series of muscle contractions. The output of the processor is the "envelopes" of the rectified signal. If the value of a given "envelope" is above a certain predetermined threshold at a certain moment, the contraction of the muscle associated with this envelope is a digit in a command word. If the "length" of this envelope is more than a certain predetermined interval of time, the digit is 1; if the length of the envelope is less than the designated interval of time, the digit is 0. Thus, one can easily transfer any set of muscle contractions to a "binary command." As far as the operator is concerned, the process of transferring comman word to the algorithmic level is equivalent to transferring a word by what is called Morse Code. A "short contraction" (the digit 0) is the dot, and a "long contraction" (the digit 1) is the dash. Since a command may include n digits, the repertoir of commands is of 2^n different commands.

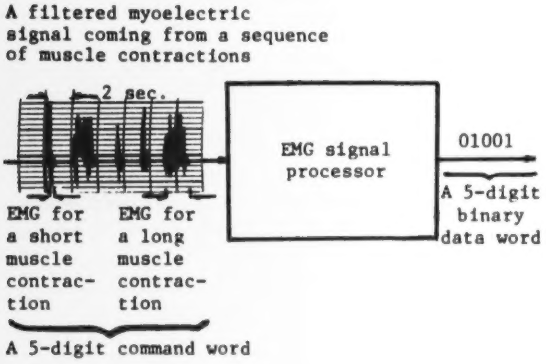

A filtered myoelectric signal coming from a sequence of muscle contractions
2 sec.
EMG signal processor
01001
A 5-digit binary data word
EMG for a short muscle contraction
EMG for a long muscle contraction
A 5-digit command word

Fig. 1 EMG signal processed to a binary code.

CLASSIFICATION OF COMMANDS

In order to efficiently control the system, we have defined two classes of commands: (i) commands that initiate a motion, and (ii) commands that stop a motion. The computer recognizes a given command as a stopping command only if the motion is already in progress. Otherwise (there is no motion) the command belongs to class (i). A stopping command (class (ii)) is one muscle contraction. An initiating-motion command includes n (arbitrary) number of muscle contractions. As far as the computer is concerned, a command that initiates a motion is a binary word with n digits (n is a fixed number for all class (i) commands). Hence, the computer "knows" how to perform the motion (the content of the word) and when to initiate the motion (after reading the n-th digit). The content of any command word includes information such as the direction of the motion, the final position, hand orientation, rate of motion, etc.

THE EXPERIMENT

We used man-interactive computer simulation to study this method. In a real-time experiment, the operator drove a three-links model of an upper extremity simulated on the MINC II (PDP 11) minicomputer graphic terminal (see Fig. 2). The subject communicated with the computer by means of an EMG signal from surface electrodes, located on one site on his arm. The EMG signal was measured on the flexor carpi radials muscle (near the medial epicondyle of humerus) for one set of experiments and on the biceps brachii muscle for the other set of experiments. In each experimental run, the raw EMG signal was passed through a high-gain differential input preamplifier, Grass Instruments Model 7P5 (low cut-off 3 Hz 3 dB point) and a driver amplifier, Grass Instruments Model 7DA (high cut-off 35 Hz 3 dB point). Next the analog EMG signal (a chart of this signal is given in the left side of Fig. 1) was sampled through the A/D converter and processed to a binary code.

Fig. 2 A man interactive computer simulation of a three degrees of freedom prosthetic arm controlled by an EMG signal. The signal was measured by surface electrodes located at one anatomically chosen site. Note that the destination of the hand is shown on the screen by the letter V.

After learning a set of commands whose length was 4 digits, and after a short training period, the subject exhibited the ability to easily transfer the three-joints model of a prosthetic arm from any given initial position to any given destination. The algorithm enabled the operator to reach the destination accurately.

APPLICATIONS

This method can be applied to any mechanical system controlled by a disabled person. Some of its possible applications are the following: a prosthetic and orthotic arm, a wheelchair-driven by a handicapped person, self-feeder, and a page-turner.

Wheelchair as an Example

The use of a microprocessor in a wheelchair control device allows designers to implement the method given in this paper. Assume that four different directions of motion are available for the wheelchair (forward, back, right, left). Following the idea of an EMG signal processed to a binary code, the repertoire of commands of class (i) is $2^2 = 4$ for this case. To stop the motion of the wheelchair one muscle contraction is sufficient (since the microprocessor recognizes one muscle contraction as a stopping command if the motion is in progress). Hence, using this procedure one can control wheelchair motion completely by using at most two voluntary muscle contractions per command. Clearly, if we want to give the operator the ability to control the wheelchair in eight different directions, the number of muscle contractions required for this option is three.

DISCUSSION

In this paper we have presented a method which gives the handicapped the ability to control a driven prosthetic or orthotic arm, or another electromechanical device using an EMG signal coming from surface electrodes located at a single site. The method described is not limited by the location of the surface electrodes. It has been found by man-interactive computer simulation that after learning a set of appropriate commands, the operator can drive a mechanical system involving several degrees of freedom efficiently and with minimum effort.

REFERENCES

1. Childress, D.S., "Powered Limb Prostheses: Their Clinical Significance," IEEE Trans. Vol. BME-20, 1973, pp. 200-207.
2. Wirta, R.W., Taylor, D.R., Finley, F.R., "Pattern-Recognition Arm Prosthesis: A Historical Perspective - A Final Report," Bulletin of Prosthetics Research, Fall 1978, pp. 8-35.
3. Graupe, D., Magnussen J., Beex, A.A., "A Microprocessor System for Multifunctional Control of Upper-Limb Prostheses Via Myoelectric Signal Identification," IEEE Trans. Vol. AC-23, 1978, pp. 538-544.
4. Graupe, D., Salahi, J., Kohn, K.H., "Multifunctional Prosthesis and Orthosis Control Via Microcomputer Identification of Temporal Pattern Differences in Single-Site Myoelectric Signals," J. Biomed. Engng. Vol. 4, 1982, pp. 17-22.
5. Mann, R.W., "Cybernetic Limb Prosthesis: The Alza Distinguished Lecture," Annals of Biomedical Engineering Vol. 9, 1981, pp. 1-43.
6. Tomovic, R., Bellman, R., "A System Approach to Muscle Control," Mathematical Biosciences, 1970, pp. 265-277.
7. Whitney, D.E., "Resolved Motion Rate Control of Manipulators and Human Prostheses, "IEEE Trans. Vol. MMS-10, 1969, pp. 47-53.
8. Whitney, D.E., "The Mathematics of Coordinated Control of Prosthetic Arms and Manipulators," Journal of Dynamic Systems, Measurement and Control, December 1972, pp. 303-309.
9. Hogan, N., "A Review of the Method of Processing EMG for Use as a Proportional Control Signal," Biomedical Engineering, March 1976, pp. 81-86.
10. Shwedyk, E., Balasubramanian, R., Scott, R.N., "A Nonstationary Model for the Electromyogram," IEEE Trans. Vol. BME-24, 1977, pp. 417-424.

Department of Biomedical Engineering
Rensselaer Polytechnic Institute
Troy, New York 12181

8.10P ONE FUNCTION TONGUE INTERFACE FOR A CHILD WITH SEVERE CEREBRAL PALSY

V.A. LITTLEMAN, O.T.R. and C.L. COSTIGAN, O.T.R.
MAPLEWOOD SCHOOL, EDMONDS, WASHINGTON

ABSTRACT

This paper presents the development of an interface controlled by tongue movement for a severely disabled child with cerebral palsy. A review of the literature indicates that commercially available tongue interfaces have primarily been used with spinal cord injuries (i.e., the sip and puff.) The reason for this is that many people with severe cerebral palsy have pathological tongue thrusts and do not have voluntary control of their tongue. This is a case study of a severe athetoid quadraplegic whose most consistent movement is with his tongue. Since there are no commercially available tongue interfaces to meet the unique needs of this particular child, a custom made interface was designed. The four year process of evaluation, training, designing, and re-designing of the interface is discussed.

INTRODUCTION

New doors continue to open for disabled persons as a result of commercially available sophisticated technology. High technology devices allow for increased control of environmental and other daily living activities. While these devices are available, the problem for many is the ability to operate them. This is due to the severity and uniqueness of their handicap. Therefore special controls need to be designed to enable these individuals to interface with specific devices. To activate a device requires a consistent motor movement which many persons with cerebral palsy lack. Designing and fabricating an interface switch coupled with intensive user training is a complex and dynamic process which may go on for many months.

Davy is one example of a severely disabled child who is unable to use commercial aids without the help of a custom-made interface. Davy is a 14-year old non-vocal child completely dominated by abnormal reflexes in all positions. Symmetrical positioning is difficult due to continuous fluctuations of muscle tone. He is unable to maintain head in midline as head is either locked in an asymmetrical tonic neck reflex to the right or left with severe extension, or when tone is low his head is forward shaking with a severe tremor. He has no voluntary control of any part of his body except tongue protrusion, retraction, elevation, and depression. Although he has the cognitive ability and desire to communicate, he lacks the physical ability to do so.

Davy attends two schools daily - Maplewood, a self-contained center for severely disabled persons and a regular elementary school. He begins his day at Maplewood receiving intensive Occupational, Physical, and Speech therapy as well as Academic tutoring services in a classroom. The Maplewood team uses a neuro-developmental approach. His Special Education goals are to prevent contractures and deformities, to increase mid-line orientation, to increase wheelchair sitting tolerance, to identify and establish consistent motor movements for communication purposes, to develop an interface switch, and to develop a communication board. The remainder two thirds of the day Davy spends in a regular 6th grade class with the help of a full time assistant.

Davy is able to say one to two words with great effort, but much of this vocalization is unintelligible. He uses tongue clicks to answer yes or no questions. In the classroom he uses a communication grid system in which Davy clicks the appropriate number of times for the column and row to indicate the phrase he wants. This system is extremely slow, laborious, and limiting.

BACKGROUND

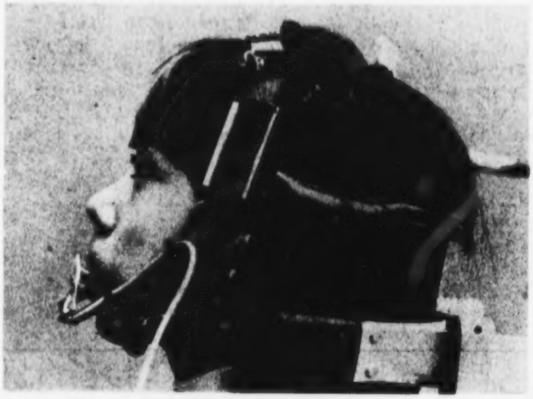
Considerable time has been spent identifying and developing a consistent motor movement and developing a functional interface switch. At one time a treadle switch activated by the left foot, hands, lateral head movements and left shoulder were tried. Unfortunately, none of these movements were consistent or reliable.

Davy's highest motor skill continues to be tongue clicks and tongue protrusion, (not pathological thrust.) Commercial switches that respond to these movements are not available. A simple microswitch device was made to evaluate the viability of using a tongue protrusion movement. Mounting the microswitch to the child was extremely difficult; tactile hypersensitivity triggered an asymmetrical Tonic Neck Reflex and extraneous movements of the jaw caused the microswitch to slip off the chin. To alleviate the tactile sensitivity problem of having anything come in direct contact with the child's head and face, an acoustic sensor switch was tried. The child was able to click into a microphone which interfaced with an Apple II computer. Not all of the child's clicks were heard by the sensor due to interference by respiratory noises. When the sensitivity of the microphone was increased, respiratory sounds were interpreted as clicks. It was decided that the tongue-operated interface offered the greatest potential and efforts were again directed in that area.

A program was intitiated to decrease tactile sensitivity around the face and head. As the child became more accepting of tactile input the interface mechanism was easier to put on. There continued to be a problem with the mechanism staying in place due to extraneous head and jaw movement. The tongue-operated, electromechanical interface was held to the lower jaw by a plastic chin cup and attached to his head with a hairnet. The switch portion was a chin cup supporting a microswitch to which a lever had been attached. The lever extended to a round target which was positioned in midline, approximately 1 cm. from the child's lower lip. A forward thrust of the tongue forced the lever forward, activating the microswitch. There were continual problems with the mechanical or structural malfunctions of this microswitch. The main causes for malfunction and inability to hit the target were: a) saliva caused the mechanism to stick; b) continual movement of lever would cause the target to bend and change shape thus putting it out of child's tongue reach; c) emotional factors, i.e., expectation to perform, fear of failure contributed to the inconsistency of motor response in operation of the switch; 3) continual problems to maintain symmetrical positioning in the wheelchair and midline orientation of his head would cause the switch to slide off the chin.

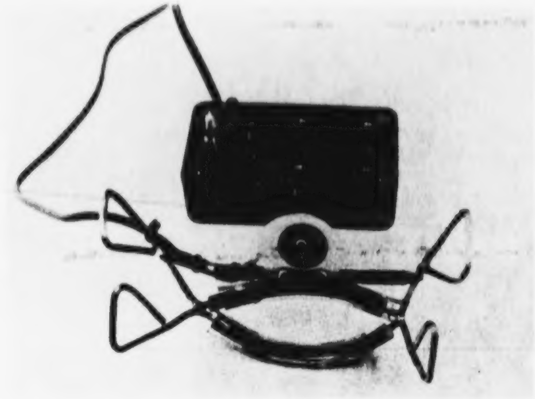
The problems of this child not being able to operate this interface consistently were analyzed and prioritized. Systematic training activities, positive reinforcement, and successful experiences decreased Davy's fear of failure and increased his willingness to try. Initial activities were highly motivating and of short duration including the use of battery operated toys and simple games which required repetition of tongue movement (in and out.) Activities were then graded to increase accuracy, i.e., accuracy with auditory cueing and accuracy with visual cueing. Initial activities were all variations of cause and effect. The next series of activities stressed scanning which requires less movements but exact timing of the movement in order to hit the switch on cue.

With the help of a technical consultant, the mechanical and positioning problems of the interface were greatly reduced. Over three years, several prototypes were constructed and evaluated - each superior to the previous model. The present model consists of a bridle made from metal tubing to fit tightly over the chin and conturing the child's face. A new head halter was made to allow precise fit and to prevent slippage.



CHILD USING TONGUE INTERFACE

A tongue-operated solid state device with no moving parts was attached to the metal tubing. The switch was positioned away from the mouth to decrease contact with saliva. This device is held stationary approximately 1 cm. from the lower jaw by a metal brace with a tension controlled elastic support. The actual switch portion consists of an insulated metallic target, connected by a cable to a type of proximity detector. When the child's tongue touches or comes within 1 mm. of the target, the device activates and the switch is closed. The sensitivity of the metallic target to touch can be adjusted. This reduces the amount of pressure needed to activate the switch. Because there are no moving parts, the mechanical problems have been reduced. The electronics portion is located separately from the target and is powered by a standard 9-volt transistor battery.



TONGUE INTERFACE WITH ELECTRONICS

WITHOUT HEAD HALTER

Midline positioning continues to be a major problem, which makes it difficult for Davy to look at what he is doing. Various wheelchair angles and adaptations have been tried. The use of an adaptive had rest to hold head in midline is being explored. However, with the interface secured tightly to Davy's chin, he is able to make contact with the sensor regardless of head position.

CONCLUSION

The interface developoment for this child was complicated by the difficulty in identifying and training a consistent motor response. Many professionals, i.e., physicians, therapists (OT, PT, CDS) had tried various motor movements with no success. The tongue was not seriously considered as a viable option due to the fact there were no commercially available interfaces that could be tried. In addition, asymmetrical positioning and difficulty tolerating being in his wheelchair for any length of time were major problems. Lack of midline orientation prevented him from looking at screen, toys, etc. Emotional factors also contributed to difficulties in evaluating a motor response. These factors combined with his extremely severe physical involvement and inconsistencies from day to day has made development of an interface very difficult.

With the use of the present interface switch, this child is experiencing increased success. The switch stays on his chin, and can be activated regardless of head position. The mechanics of the switch are much more reliable. Yet, there are further refinements that need to be made. A redesign of the sensor mounting system is in process to eliminate activation by accumulation of saliva. All this in turn has made him more willing and less anxious when using the interface. This interface requires less physical effort which in turn decreases stimulation of abnormal reflexes. Because Davy's physical, academic, social, and communication needs will continue to change, his use of the tongue interface will need to be continually monitored and updated. The current tongue switch model allows Davy to operate an Apple II computer to play simple games, to write out messages using an alphabet scanning system, and to compute math problems. The interface allows the child to try various electronic communication systems and will increase independence in academic skills.

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ADDRESS

V.A. Littleman, OTR
Maplewood School
20100 84th Avenue West
Edmonds, Washington 98020

FIVE INEXPENSIVE INDEPENDENT LIVING AIDS

9.1

Leonard L. Anderson, M.S.E.M.

Cerebral Palsy Research Foundation of Kansas, Inc.
Rehabilitation Engineering Center

ABSTRACT

The Rehabilitation Engineering Cen-in Wichita, Kansas, has, as its emphasis, research in the area of placing severely disabled persons in the workplace. The "Timbers" is an Independent Living Center in Wichita where many of the clients live. In providing support for the disabled worker the place where he or she lives, and the desire for increased independence, often must be considered. Independence at home tends to "spill over" into the workplace. Members of the R.E.C. have worked with several clients in an effort to make their home life more independent.

INTRODUCTION

The "Timbers" is an Independent Living Center in Wichita, Kansas. Emphasis is placed on providing independence for severely disabled adults in the home environment. "Timbers" was developed under the sponsorship of the Cerebral Palsy Research Foundation of Kansas, Inc., and is a H.U.D. Section 8 project having 100 housing units.

The Rehabilitation Engineering Center of Wichita is federally funded by the National Institute of Handicapped Research, and is also under the sponsorship of C.P.R.F.K. Members of the R.E.C. have designed, fabricated, and installed several devices at the "Timbers" to aid residents in being more independent of services than they would be without the devices. Five such devices are presented here.

DEVICES

Light Weight Headwand

Persons who do not have use of their hands often type, turn pages of a book, etc., using a head-mounted wand (or stylus). Most commercially available headwands are fairly heavy and the stem of the wand extends downward from the forehead and is centrally located, between the eyes, making it necessary for the user to look "around" the wand.

A light weight headwand has been developed which utilizes a side-mounted wand of aluminum tubing and a headgear which is made of nylon and was originally intended to be the adjustable liner for a welder's helmet. See Figure 1.

Features of the unit include adjustment of the headband for size, adjustment of the stem of the wand for length, and a sponge pad for the forehead. The sponge pad usually provides enough friction on the forehead making a chin strap unnecessary for average use.

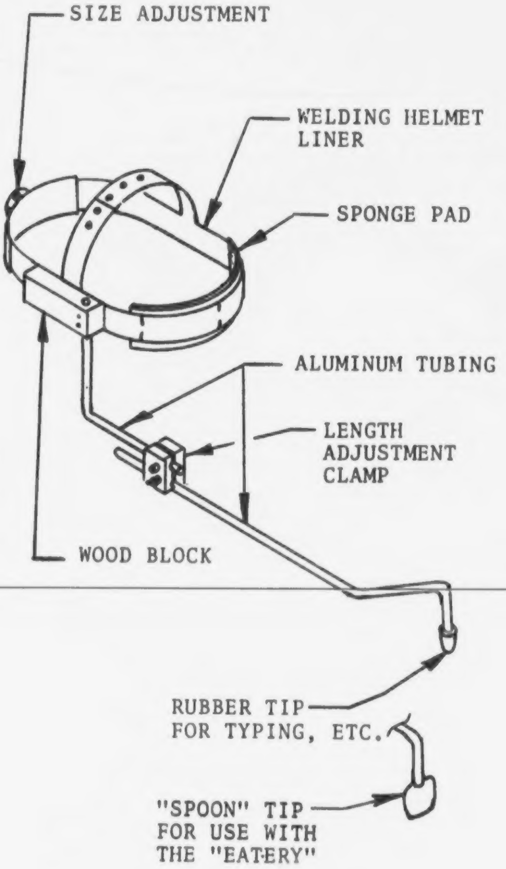

FIGURE I: HEADWAND

The "EATERY"

A very simple inexpensive device has been developed to allow persons who are unable to use their hands to feed themselves. Anyone who has sufficient control of their head to type using a headwand should be able to use this device called the "Eatery".

The idea was that of a woman in Washington, Kansas, who, when she was bedfast due to polio, was unable to eat without someone else feeding her. Having been able to eat by herself prior to that time she yearned for that degree of independence. She recovered and was later able to feed herself.

A friend of hers who has severe quadriplegia due to cerebral palsy was desirous of eating independently. Knowing, first-hand, the importance of this achievement, she put her ingenuity to work and this device is the result. Members of the R.E.C. took her idea and developed the product which is now available to be purchased through C.P.R.F.K.

The principle is simple. The user employs the use of a headwand similar to the one shown in Figure 1, except the rubber tip is replaced by a spoonshaped blade. A special plate is used which has deep sides, three partitions, and two "spoon" shaped projections on one side. The special plate is held in place by Velcro strips on a surface located at chin height to the user. The headwand is used to move food particles from the inner plate onto the "spoon" projections and the user simply takes the food directly from the "spoon" with his/her mouth. Five residents of the "Timbers" use this device daily and some 20 units have been sold to date. See Figure 2.

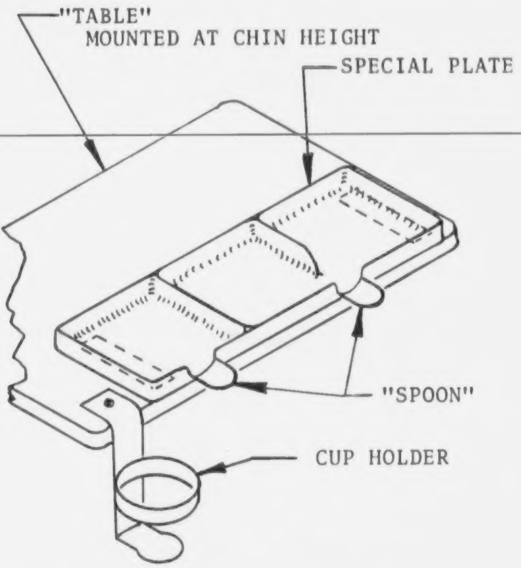

FIGURE 2: THE "EATERY"

Automatic Washer Controls

Washing machines at the "Timbers" have a dial-type selector control which is located at the top and to the rear of the machine making it difficult for wheelchair users to reach. Senior engineering students at Wichita State University designed and installed an adaptation which effectively moves the control knob to the front. See Figure 3.

Features of the device include an expanded dial for ease of interpretation, and lever arms that provide for less force to be applied to rotate the control.

Dryer Controls

Clothes dryers at the "Timbers" have pushbutton controls mounted at the top and at the rear of the machine which also makes it difficult for wheelchair users to reach. Senior engineering students at Wichita State University have also adapted the controls for the dryer as shown in Figure 4.

Significant features are large size pushbuttons with adequate separation and an expanded controls display.

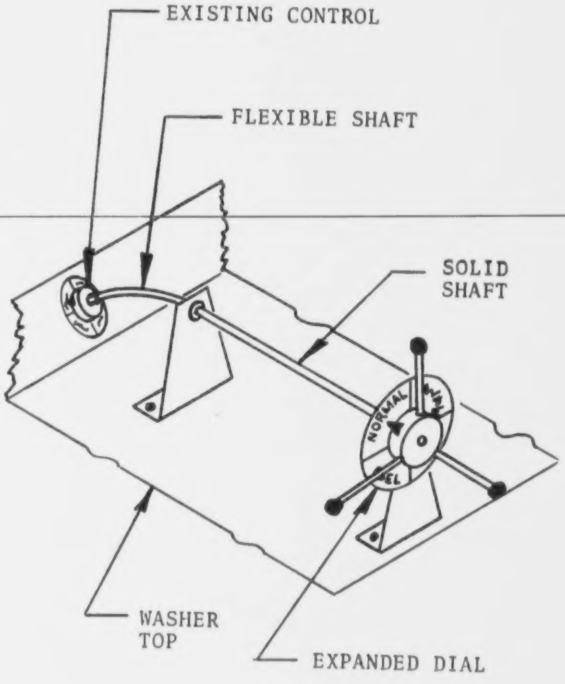

FIGURE 3: WASHER CONTROLS

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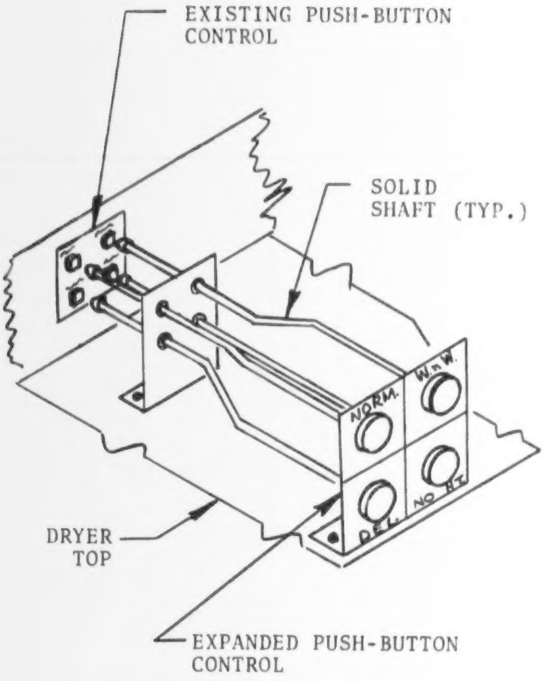

EXISTING PUSH-BUTTON CONTROL
SOLID SHAFT (TYP.)
NORM.
W.n.W.
DEL.
NO HT.
DRYER TOP
EXPANDED PUSH-BUTTON CONTROL

FIGURE 4: DRYER CONTROLS

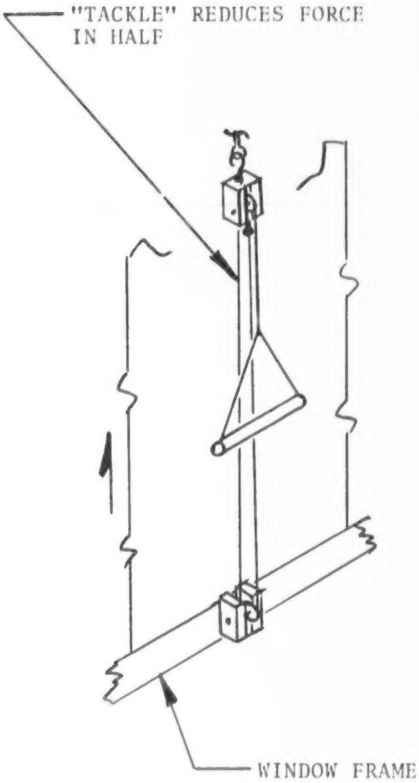

"TACKLE" REDUCES FORCE IN HALF
WINDOW FRAME

FIGURE 5: WINDOW LIFTER

Window Opening Aid

One resident at the "Timbers" was not able to raise his window for fresh air when he was desirous of doing so. He could push the window downward in its track, thus closing it, but did not have sufficient strength to raise it.

A small block and tackle was rigged on the windows of his apartment to aid him in the operation of the windows.

Of significance is that the device not only reduces tha raising force required to raise the window by one-half, but the motion required to raise the window is downward, which is the direction in which this resident has the most strength. See Figure 5.

CONCLUSIONS

The devices mentioned herein are all in use, are inexpensive, and are providing for signicant independence for the residents at the "Timbers".

ACKNOWLEDGEMENT

The author wishes to acknowledge the National Institute of Handicapped Research and the Rehabilitation Engineering Center for support for this research activity.

Leonard L. Anderson
Director of Engineering
Cerebral Palsy Research Foundation
2021 N. Old Manor
Wichita, Kansas 67208
(316) 688-1888

9.2 DEVELOPMENT AND APPLICATION OF INEXPENSIVE INDEPENDENT LIVING AIDS

Charles J. Laenger, Sr.
Rehabilitation Engineer
Tulsa Rehabilitation Center
Tulsa, Oklahoma

Bill Brinnon
Director of Manual Training
Tulsa Independent Living Center
Tulsa, Oklahoma

ABSTRACT

Elderly and long-term disabled people often cannot afford assistive devices. They certainly cannot afford engineering and fabrication costs for special devices. A unique "community" exists in Tulsa Oklahoma, where an independent living center, recreational facility for disabled, residential complex and rehabilitation center collaborate to, (1) identify special independent living aids needs, (2) generate design solutions, (3) fabricate prototypes and functional devices and (4) disseminate pertinent information. Devices are fabricated by volunteers and disabled participants in recreational programs. Prototype devices are displayed in the Tulsa Independent Living Center.

INTRODUCTION

Cost is the primary factor that limits utilization of independent living aids. Other limiting factors are availability of technical assistance and information and availability of the devices themselves. Potential users are ordinarily handicapped due to inadequate communication and inadequate transportation. In addition, their advocates and service providers are often more uninformed than they.

A unique and productive setting whereby many of the special independent living aids needs of the disabled people in the Tulsa, Oklahoma, area are being satisfied. Key component organizations of this peculiar "community" are as follows: (1) the Rehabilitation Engineering Department of the Tulsa Rehabilitation Center;[1] (2) the Tulsa Independent Living Center;[2] (3) the Tulsa Center for the Physically Limited;[3] (4) Aliene Murdock Villa (an apartment building for disabled);[4] (5) the Recreational Therapy Department CRISP program at the Tulsa Rehabilitation Center.[5] All of these components routinely interact with elderly and disabled people which facilitates a continuing flow of independent living aids needs and problem identification.

Technical information and designs are provided by the Tulsa Rehabilitation Center. Fabrication effort is provided by users of the Tulsa Center for the Physically Limited and staff members and volunteers of the Tulsa Independent Living Center under the direction of their Director of Manual Training. Needy disabled people are provided many of the special aids that they need at cost of materials only!

MATERIALS AND METHODS

Potential users present problems and needs to the programs and facilities listed above. The Director of Manual Training, a volunteer who was formerly a geophysicist, designs and fabricates certain aids independently. Screened and more difficult problems are referred to Tulsa Rehabilitation Center. Preliminary designs and design ideas are returned to the Tulsa Center for the Physically Limited program where prototype devices are quickly and inexpensively fabricated by participants in the Tulsa Center for the Physically Limited program and by volunteer staff. If the device proves appropriate, a functional copy is fabricated for the client. Re-design is performed collaboratively by staff members of the Tulsa Independent Living Center, Tulsa Rehabilitation Center and the Tulsa Center for the Physically Limited.

RESULTS

Examples of independent living aids developed and applied by the cooperative and informal "program" are as follows:

1. Modified telephone dialer for stroke victims. Certain disabled people cannot use automatic dialers because they do not have the dexterity required to depress small buttons. A very inexpensive modification was made to a Radio Shack Automatic Memory Dialer by simply fabricating and placing an overlay over the keyboard. This overlay reduced the number of available telephone numbers from sixteen to four, however, it increased the target area from 0.05 square inch to about 1.25 square inch or about 25 times. This modification significantly improved the ability of several patients to use the telephone independently. See Figure 1.

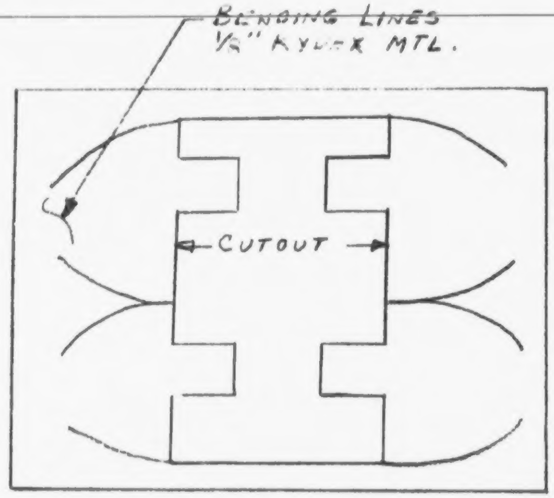


Figure 1. Overlay For Radio Shack Automatic Memory Dialer.

2. Contact lens remover for quadriplegic. A quadriplegic client who wore hand splints requested a device which would enable him to

change his contact lenses independently. He could hold a pencil between his thumb and forefinger with the aid of his splint.

The end was cut from a contact lens remover and it was coupled to a two-foot section of 1/8" rubber hose. The patient simply exerts negative pressure, through suction, on the lens via the hose and lens remover. He successfully installs and removes his contact lenses with this simple independent living aid.

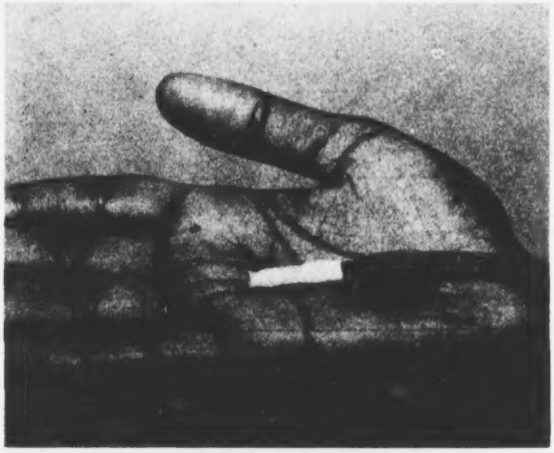


Figure 2. Contact Lens Remover - Remover Coupled To 1/8" ID Rubber Hose.

Figure 3. Application Of Contact Lens Remover

3. "Rolledex" Communicator For Severely Disabled. A stroke patient was dysarthric and suffered from athetosis. The primary cause of severe frustration was inability to communicate. She was unable to utilize communication assist devices because of poor dexterity and control. When attempting to operate a pushbutton switch, she would either "lock-up" on it or make multiple actuations.

A Radio Shack Desk Top Automatic Directory 43-105 apparatus was modified to suit her need. Appropriate messages were placed in the card holders. Typical messages were: "I am cold" and "I want water", but her favorite was "Go to hell".

The device was modified as follows: (1) the keyboard was electrically bypassed, (2) a normally open jack was installed to permit operation by an external momentary contact switch and (3) the circuit was modified to "pulse" the D.C. motor, that is, to assure the advance of one and only one card per activation. See Figures 4 and 5.

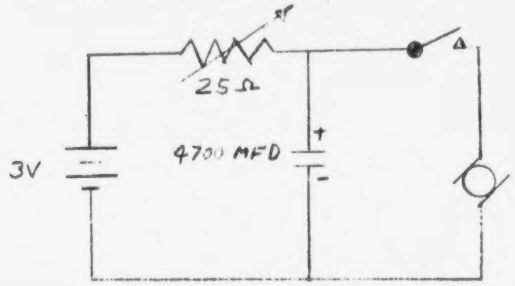


Figure 4. D.C. Motor Pulsing And Hold-off Circuit (Modified Automatic Directory)

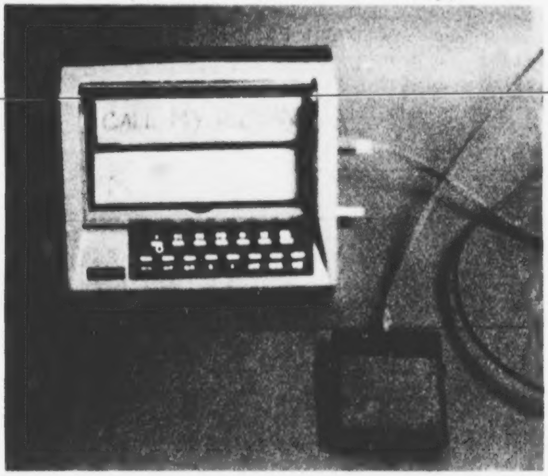


Figure 5. "Rolledex" Communicator For Severely Disabled. (Modified Automatic Directory)

4. Key Slot Expander For Deaf Quadriplegic. A disabled occupant of Murdock Villa did not have sufficient dexterity to insert his door key into the lock. A tapered hole or funnel device was made and attached to the door lock; in effect, a larger "target" was made. This assist device enabled the disabled individual to access his apartment independently.

5. Staple Puller For People With Weak Hands.
   An outpatient who performed office work was unable to operate a staple puller. She had arthritis in her dominant hand.

   A foot-operated staple puller was fabricated from a gate hinge, bicycle gear control cable and selected steel springs. See Figure 5.

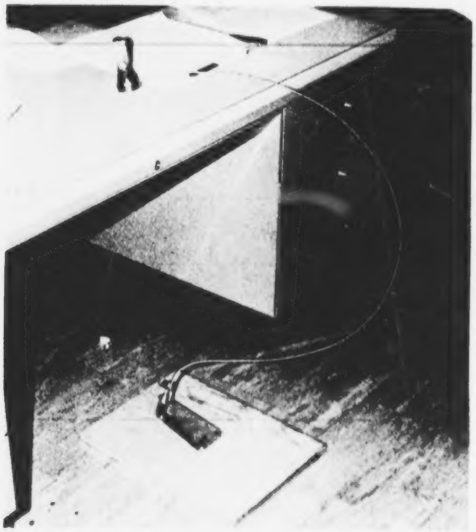


Figure 6. Foot Operated Staple Puller.

6. Can Openers Modifications
   Both manual and electric can opener modifications have been made to suit the specific needs of disabled individuals.

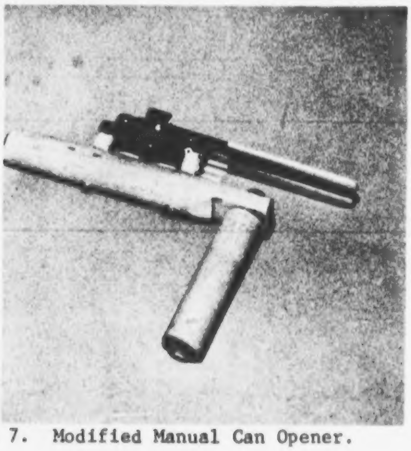


Figure 7. Modified Manual Can Opener.

7. Security Lock Card Key Holders.
   A new security system which requires insertion of special cards into a machine was installed at Murdock Villa. Certain ones of the disabled residents could not perform the insertion procedure without help. Four special holders of varying geometry were fabricated and used for trial and prescription purposes. After appropriate selections were made, individual aids were fabricated in the Tulsa Center for the Physically Limited carpenter shop.

8. Telephone Assist Devices.
   Various telephone assist devices were fabricated from Kydex and installed to assure function and to make appropriate demands on the individuals physical capability.

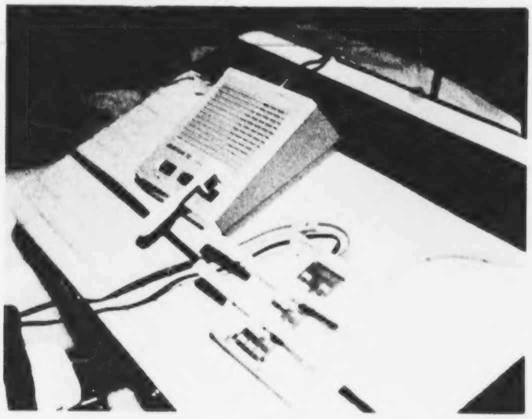


Figure 8. Automatic Dialer And Speaker Phone Modification For Independent Operations.

CONCLUSIONS

Any successful program for development and application of functional and inexpensive independent living aids must have a self-perpetuating source of problems and identification of needs. Through appropriate management and supervision, much of the fabrication can be accomplished by disabled people themselves. Designers and fabricators of low cost independent living aids must learn to modify existing devices and to acquire components from inexpensive sources such as the local hardware store.

REFERENCES AND ACKNOWLEDGEMENTS

1. A modified IMPART program, established under NIHR Grant No. G008003085 which continues to operate at this center.
2. Established by a Noble Foundation Grant; expanded and currently funded by NIHR Grant No. G008202673.
3. Supported by local funds and donors and self-generated income.
4. Immediately adjacent to the Tulsa Independent Living Center and Tulsa Center for the Physically Limited. Building erected through HUD program.
5. A continuing program of Tulsa Rehabilitation Center; established under NIHR Grant No. B008104521

Charles J. Laenger, Sr.
Tulsa Rehabilitation Center
1125 S. Trenton
Tulsa, Oklahoma 74120

EQUIPMENT MAKES THE DIFFERENCE

9.3

Arthur Heyer

EXTENSIONS FOR INDEPENDENCE

ASSISTIVE EQUIPMENT SAVES TIME AND MONEY. IT MAKES LIFE EASIER AND HAPPIER FOR EVERYBODY, IN THE FAMILY AND OUTSIDE THE FAMILY. IT DIGNIFIES AND MAKES DISABILITY A NATURAL PART OF A FAMILY'S LIFE: THE DISABLED BROTHER BECOMES A BROTHER WITH SPECIAL NEEDS, NOT A BURDEN OF THE FAMILY.

Assistive equipment has been a crucial part in my life since I became quadruplegic 19 years ago at age 17. The majority of this equipment has not been immediately available to me, however. It has been created to solve my needs, and then perfected through the years. New equipment is still being created around these needs. It seems that there is no end to it.

In the following paragraphs I will describe some of this equipment and how it has been beneficial to me and those around me. I will not talk about my power wheelchair or my van arranged with a lift, which are also so important in my life. I will only talk about the equipment which has been designed around my needs and which could have application to the needs of other quadruplegics. Note: This paper includes an up-dated review of the H-A Modular Mouthstick, which I consider my most functional assistive device, and which was fully described in a paper presented in Toronto in 1980.

HEYER-ABADIE MODULAR MOUTHSTICK.

This mouthstick has been the result of years of research and development, and many years of daily experience working with one similar to it. It has been and it is the cornerstone of my functional independence for work and study. It is a simple, yet most versatile piece of equipment. If my mouthstick was taken out of my mouth when I need it, it would be just as frustrating as if an artist was deprived from painting.

With my mouthstick, I can type 22 words per minute, use the telephone, write long hand, do filing, literature research, and do drafting!

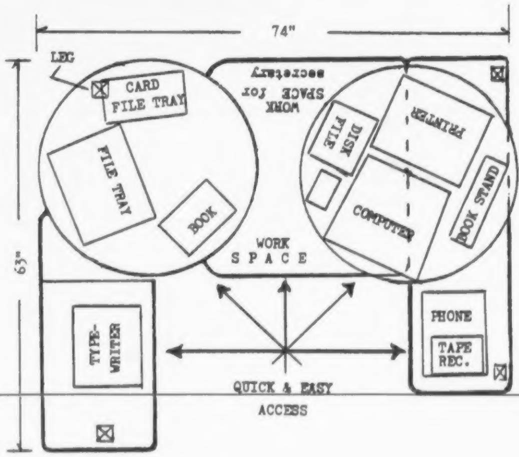
This mouthstick has important features which make it unique in performance capability. The mouthpiece is flat and "V" shaped, to be gripped with the molars of both sides, leaving room in the middle for the tongue to move, and a free path in between the front teeth for air to flow out of the mouth, two characteristics which are essential for talking. Also, it is important to note, that allowing the tongue to move freely, makes swallowing easy.

The mouthpiece, made of aluminum, is the basic unit to which any of several different mouthstick "bodies" or "modules" can be attached. For example, if someone is only interested in turning pages or typing, we have a feather-weight mouthstick "body" with a rubber tip.

With the addition of a module, the basic featherweight mouthstick becomes a telescoping mouthstick. In this mode, the mouthstick can be extended to almost double its original length.

The telescoping feature can be combined with a module which has a mechanism for independent interchange of implements by the mouthstick user. With this arrangement, the mouthstick user can interchange from an eraser tip for turning pages ...to a pen or mechanical pencil for writing notes.

"U" MODULAR TWIN-TURNTABLE DESK



A turntable as a desk is ideal for persons with limited reach. It provides easy access to a number of things by just rotating it.

We redesigned out Single-Turntable Desk so it can be made into a low-cost, built-up as needed, "U"-shaped Twin-Turntable Desk with the addition of two Extension Tables and a Self-Standing Turntable.

One Extension Table makes the Single-Turntable Desk in an "L" shape. A second Extension Table extends the length of the desk and makes it "U" shaped.

The extended desk can then accept a second turntable that can be placed on top. The resulting U-Shaped Twin-Turntable Desk, composed of four modular sections, makes a highly functional workstation for the wheelchair-bounded student, clerk, or businessman.

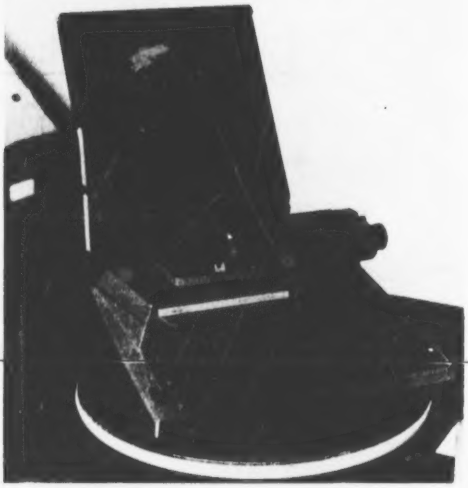
On one turntable, I have files and other reference material. On the other turntable, I have a complete data processing system, consisting of a personal computer and a printer.

The telephone is on the Extension Table of the side next to the computer, and I have a typewriter on the other Extension Table, next to the turntable which contains the reference material.

In this manner, I have easy and immediate access to all the reference material while working with the computer, or while working with the typewriter.

Being on a turntable, the personal computer is also accessible from the position of using the telephone. The printer, which we have made fully operational with a mouthstick, is easily accessible when necessary, and out of the way when not in use.

TYPEWRITER PAPER-LOADER



My functional independence was very incomplete without a mechanism for independent loading of paper into my typewriter. So I sat in front of my typewriter and dreamed about a way to do it. I built up a mechanism in my mind, and played with it until I was sure of what I wanted. I then made sketches and discussed the matter with one of my shop workers.

We built two types of paper loaders for two different types of typewriters: Type I, for a conventional portable typewriter, and Type II, for a larger single-element typewriter.

An inherent feature of these paper loaders is that they accept any type of material, such as envelopes, cards, forms, or sets with carbons.

The Type-I paper loader folds backwards to convert itself into a ramp. Paper may be fed directly from a file tray, or from the desk top. A feature in the design prevents the paper, or group of papers, from sliding backwards.

The typewriter rests on a lazy susan tray. This is necessary for the operation of this paper loader, and in order to reach for the different controls of the typewriter.

The Type-II paper loader has front access, and the typewriter does not need to be mounted on a lazy susan. Instead, this typewriter is to be tilted for better visibility. It is a single element machine, and by tilting it, the handicapped operator can more easily see what he or she is typing.

This paper loader is made of transparent acrylic and mounts easily on the typewriter. Paper can be fed from any file tray or directly from the desk top via a folding ramp.

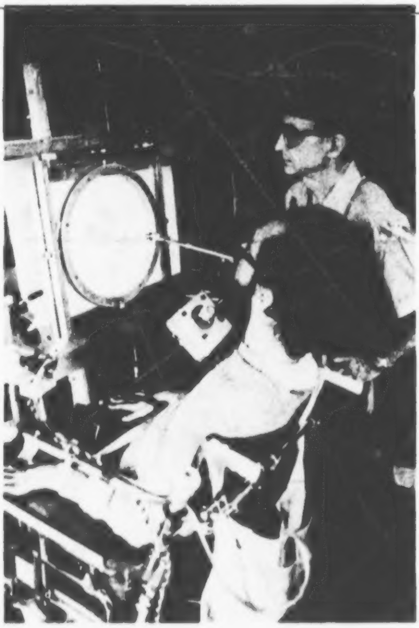
COMPUTER KEYBOARD CONVERSION ATTACHMENT FOR MOUTHSTICK OPERATION

For mouthstick users, Extensions for Independence has designed a keyboard adaptation which can be used with certain micro-computers that require pressing two or three keys simultaneously for their operation.

The adaptation consists of an acrylic frame with positioning locks for individual keys. The locks are spring-loaded tabs which automatically lock the keys when depressed. A slight push on the lock releases the key to its original position.

The adaptation modifies the keyboard only externally, and it can be snapped off in seconds when not needed.

HEYER-ABADIE X-Y DRAFTING MACHINE



EQUIPMENT MAKES THE DIFFERENCE

This is a mouthstick-operated machine for drawing straight lines and circles on 18 x 22 inch paper. The scales and circle-drawing mechanism are mounted on a large ring protractor 15 inches in diameter.

The protractor and scales, as a unit, remain within the reach of the mouthstick user, while the drawing board moves up or down or to the sides to its exact position with respect to the scales.

Once the drawing board is in the desired position, the protractor can be electrically rotated to position the scales in the desired direction for drawing straight lines or for making circles.

The motion of the drawing board, and the rotation of the protractor and scales, is done by means of a servo system controlled by a joystick similar to the control of a power wheelchair.

MOTORIZED EASEL

We designed and built a motorized easel for Joni Eareckson, the internationally known writer, speaker, and artist.

"With the tip of my finger, I can move my drawing up or down or to the sides," Joni wrote in reference to her new motorized easel.

With her motorized easel, Joni can make large paintings without needing someone to reposition the canvas for her. The motorized easel is designed to easily adjust to the needs of the user. It can be lowered, raised, or tilted to any position, and even be adjusted for use in bed.

CONCLUDING REMARKS

The strong needs that I had for functional equipment motivated me to spend thousands of hours analyzing the needs and looking for solutions. I hope that the time and effort spent in coming up with solutions to solve my own physical limitations serve to decrease the effort of others in their endeavor of making the handicapped more functional.

ACKNOWLEDGEMENTS

I want to thank all those, family and friends, for their invaluable assistance in the creation and production of this equipment. And I want to especially thank my father and Henry Abadie for their fine ideas and perseverant hard work, which have been so meaningful in the development of this equipment.

REFERENCES

1. "Engineering," Rehabilitation Gazette, 1971/ Vol. XIV, pp. 32-33.
2. "Quad Engineer Puts Talent to Work," Responaut (English Rehabilitation Journal), Sept/1972 issue.
3. "Liaison Engineer," Rehab. Gazette, 1975/ Vol. XVIII p. 17.
4. "Preparing Quads for Independent Living," Rehab. Gazette, 1976/Vol. XIX, p. 31.
5. "Custom-Designed Office for a Mouthstick User," Rehab. Gazette, 1978/Vol. XXI, pp. 38-39.
6. "Functional Independence for High-Level Quads with a 'Talking' Mouthstick and 'Peripheral' Equipment." Proceedings of the 5th Annual Conference on Systems and Devices for the Disabled, June/1978, Houston, Texas. pp.66-69.
7. "An Outstanding Example of Rehabilitation," by George Winston, TAD News, August 1979, Australia. p. 27.
8. The Heyer-Abadie "Talking" Mouthstick. Proceedings of International Conference on Rehabilitation Engineering, June/1980, Toronto, Ontario, Canada. pp. 344-347.

Address: Extensions for Independence
635-5 N. Twin Oaks Valley Road
San Marcos, California 92069

9.4

AIR DRIVEN DEVICES USING THE ORAL CAVITY AS A POWER SOURCE

C. Kerry Jones
"The Space Between"

INTRODUCTION

Air powered devices that utilize a person's cheeks, tongue, jaw and lungs can provide many novel solutions to problems experienced by those with disabilities. Often, the answers to an individual's problem become overly complicated, expensive, and reliant upon external power sources. If the individual can become the power source, then, simpler and more direct solutions can be used. Power generated by an individual's oral cavity can be extremely strong and the user need not worry about low batteries or empty gas cylinders.

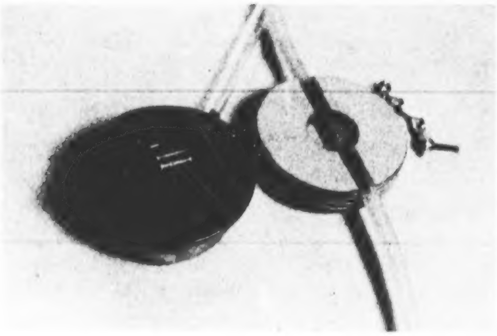
There is something magical about using one's own breath to interact with the environment. Many disabled individuals (especially those with spinal cord injuries) have lost control of their whole body, exclusive of their head and shoulders. Their cheeks, tongue and jaw are still capable of producing great pressure and vacuum. A person's mouth can be likened to an air pump, complete with one-way valves and pressure regulators. The tongue mimics a piston pump, while the cheeks act as a diaphragm pump. These two pumps can work independently of one another or in tandem. The tongue is a valve. It is capable of metering the flow in a slow, steady stream or acting as a shut-off valve that can be switched on and off very rapidly. This valve can seat itself upon an irregular surface and can even detect its own leaks.

If an individual's lungs can also be used, the variety of tasks that can be performed is even greater. The displacement of larger volumes of air can create longer stroke lengths and faster duty cycles. Any device that must be pushed, pulled or rotated can be controlled through the use of oral drive.

BACKGROUND

The initial work in oral drive devices was undertaken in a search for a leg bag valve that would not require the individual to bend over or use his hands. At the time of this search, no commercial device was available to satisfy this need. The device had to be simple, concealable, inexpensive, trouble free and require no electrical hook-ups.

The use of a vacuum motor, modified to act as a pinch valve, was decided upon after researching several alternatives. The vacuum motor is spring loaded and requires that the user sip gently upon the vacuum tube to release the pincher. Vacuum motors can be purchased with a wide range of spring forces, and the one used for the leg bag valve was chosen for its ability to pinch shut 1/4" silicone tubing.

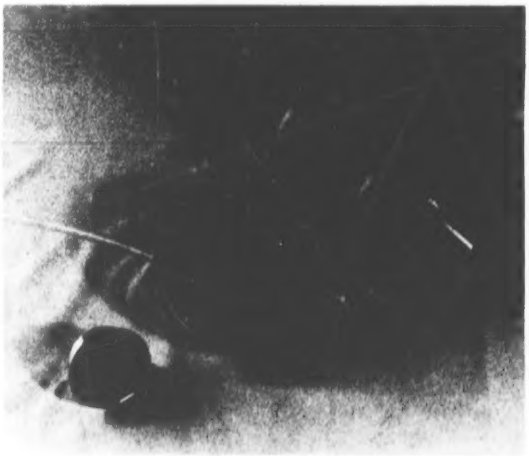


Leg Bag Users Valve (L.U.V.)
in opened position

Once the pincher has been sipped back, the user can place his tongue over the vacuum tube to hold the motor in a retracted position. The silicone drain tube is a separate unit from the vacuum motor, and there is no possibility of urine being drawn up the vacuum tube.

MATERIALS AND METHODS

There are two very basic types of oral devices, either pressure or vacuum actuated. The motors can also be separated into two types: cylinders (tube and piston) or bellows (expandable rubber diaphragms). The type chosen is dependent upon its end use.



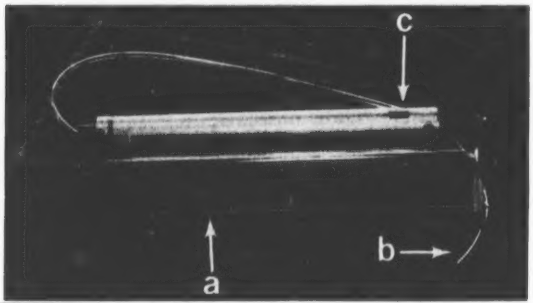
Assortment of Air Motors
2" diameter to 8" diameter

The Cylinder

The cylinder is generally used as a long stroke, low force device. Cylinders are also prone to leakage and cannot be depended upon to hold their position under load once the valve has been shut. They are suitable for positioning needs, such as the dial actuator shown in the picture below. Any rotary or linear potentiameter can be accurately positioned using oral drive. Short incremental steps or long continuous movements can be made within the same stroke. A long stroke cylinder and a small diameter dial can be used to create several turns in one stroke length. A cylinder that does not have spring return can be either sipped or puffed into position, creating bi-directional control. The use of a fairly "loose" cylinder is suggested for applications of this nature. A cylinder with a tight seal around its piston can create excessive drag.

The Bellows

The bellows, or diaphragm, oral device is used primarily where short stroke and great force is required. Due to the volume of air displaced in a larger air motor, it may take several short sips or puffs to create the desired movement. A vacuum bellows will normally have a compression spring holding the motor in an extended position. The force of this spring can be used to perform a function (such as the pinch valve). A five-inch-diameter vacuum bellows with a one-inch stroke can be caused to lift fifty pounds in a matter of seconds. To generate the maximum force, it is necessary to take short sips and use the tongue as a one-way valve between sips.



Rotary or Linear Positioner
A. 1/8" elastic shock cord
B. 1/4" vacuum tube
C. 14" stroke air cylinder

Since the bellows utilizes a rubber diaphragm, it can be used to hold an object under load without worry of air leakage.

A long stroke, large diameter bellows will require a lot of sipping and puffing, unless the client has some degree of lung capacity. A steering linkage was fabricated for use by a boy with muscular dystrophy for his soap box derby racer using a long stroke, large diameter bellows. The boy successfully steered his sleek racer at speeds in excess of 30 mph. An electric brake was installed to stop the racer at the end of the course.

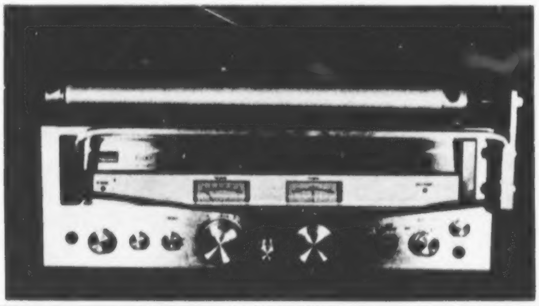
RESULTS

The Leg Bag Users Valve (L.U.V.) has been on the market for four years. In that time, over five hundred units have been sold and only two have been returned. Some of the earliest prototypes are still in use.

The single most important benefit that oral drive devices provide their users is feedback. The amounts of vacuum and pressure generated by the user can actually be felt.

The simple nature of these sytems allows troubleshooting by non-technical individuals. It is easy to detect leaks or see broken linkages. Many vacuum motors are currently used in the production of automobiles and, therefore, can be purchased through local parts houses.

Positioner, operating stereo tuner



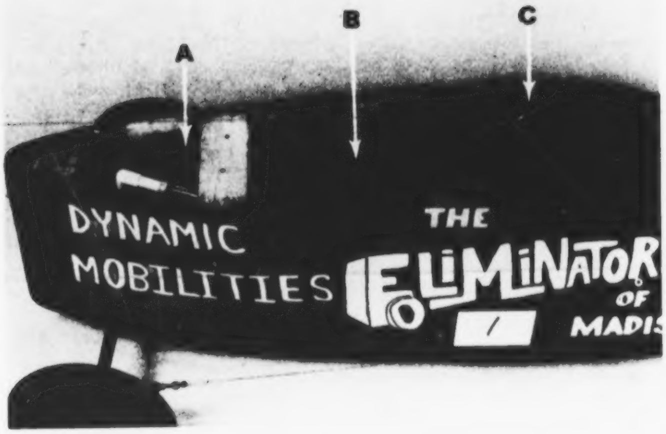
FUTURE PROJECTS

Two projects are under study for possible implementation in this year. The first is the adaption of a gas powered hand splint that will have a vacuum motor hooked in parallel to it. The vacuum oral drive will provide its user with feedback and adjustable grip strength. The standard gas powered mechanism will aid the user while he is eating, drinking, or talking.

The second project under consideration is the development of a joystick controller that can be snapped over the top of a standard electric wheelchair control box. The projected price of this unit would be 1/15 that of the standard electric puff and sip controllers now used.

ACKNOWLEDGMENTS

This research and development was funded in part by Dynamic Mobilities, Inc. and The Wisconsin Foundation for Applied Technology, both of Madison, Wisconsin.


A
B
C
DYNAMIC MOBILITIES
THE
ELiMiNATOR
OF
MADIS
1

Soap Box Derby Racer Steered by
Use of Air Motor
A. 8" diameter, 8" stroke bellows
attached to steering linkage.
Internal spring within bellows
acts as centering device.
B. Switch that activates electric brake
C. Driver's air line to bellows

C. Kerry Jones
"The Space Between"
2746 City Highway W
Route 1
Deerfield, WI 53531

THE HUMANISTIC DESIGNER - NEW PERSPECTIVES

PETER W. AXELSON M.S.M.E.

BENEFICIAL DESIGNS INC.

ABSTRACT

The time has come for an integrated approach to problem identification and problem solving for persons with disabilities. Many professionals, though trained and skillful at solving problems typically are not trained at identifying and determining the very needs they must fill.

Specialties or 'niches' are created under the guise of professional expertise and, in turn, problems which are intimately interrelated are often treated in an isolated manner . . . if at all.

As a positive alternative to the obviously lacking 'niche' approach, this paper suggests the role of a 'humanistic designer' who is able to identify needs and define problems before looking for the solutions. Whether the 'humanistic designer' is a therapist, doctor, nurse, clinician, engineer, machinist, technician or family member, the need for enlarged perspectives is crucial to encompassing the problems of the disabled and solving them.

Seeing the person with a disabiity as a 'whole' requires the exploration and understanding of many dimensions of that person's life. This paper explores the characteristics of three dimensions in relation to disability;

> The first dimension relates to experiential aspects of a persons life: i.e. living, vocational and recreational skills.
>
> The second dimension relates to the ingredients for balance in a person's life: i.e., body, mind and spirit.
>
> The third dimension relates to an individual's sociological makeup: i.e., dependence, independence and level of integration.

The interrelationship between the three dimensions is utilized in the 'humanistic design process'. Imagine the dimensions as axes. They create a three-dimensional 'space' in which the professional can move as a humanistic designer as opposed to being a problem solver at one 'point in space'. (see figure 1)

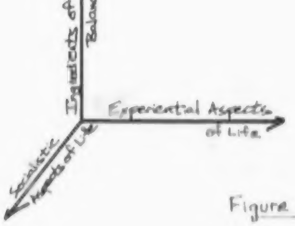


Figure 1

INTRODUCTION

People with specialized and focused skills are very useful when utilized by a team of researchers or by a large organization. Specialists can also be productively utilized when the consultee knows exactly what he or she wants. Humanistic design is difficult for specialists who like dealing with very clear and well defined problems. Unfortunately, very few clearly defined problems exist in the field of rehabilitation. This paper encourages you to step out of your specialized 'niche' and into the multi-dimensional space that encompases not just your own life but the lives of others including persons with and without disabilities.

Now that was easy to write down on paper but what does this mean? The notion of perspective is paramount to becoming a 'humanistic designer'. And becoming a 'humanistic designer' is required if you hope to solve the needs of persons with disabilities. Understanding your perspective and how to change it will allow you to better meet the needs of persons with disabilities.

Persons who are used to solving problems in a linear fashion will have difficulty meeting the needs of persons with disablities. As an example, imagine that place called Flatland[1] where the people are made up of triangles, squares, pentagons, hexagons, octagons, circles etc. (according to social stature) which live in a two-dimensional plane. Upon being questioned about the possibility of a third dimension the inhabitants of Flatland are unable to visualize anything beyond their two dimensional world. Even when being visited by a member of the three-dimensional world they are able to see only a slice of the person. One member of Flatland does go to visit a place called Lineland in which the inhabitants know of only one dimension. Each member of Lineland consists of a line, varying in length according to social stature. Each member of Lineland can only see the endpoint of the person in line with themself. The members of Lineland can see only a given point of a visiting member from Flatland and is thus unable to visualize the two dimensions of Flatland.

As problem solvers we must avoid narrow boundaries to our thinking. Rehabilitation needs can be met only if the problem solver can leave "lineland", "flatland" and venture into "space".

DESCRIPTION OF DIMENSIONS

DIMENSION ONE - EXPERIENTIAL

All of the tasks and activities in a person's life could be categorized into various types. Three very general categories of activities shall be identified as independent living, vocational and recreational. The order in which the categories of activity have been listed represents the priority in which rehabilitation centers in this country, the United States, base their activities and programming. Many governmental agencies place vocational activities at a higher priority than independent living activities. A minority of programs place recreational activities as the highest priority when making programming and funding decisions.

A humanistic designer will use the experiential dimension to identify problems when working with the disabled. For example, often a vocational activity will enhance an independent living activity and the device or system can then be improved to better meet the needs of an even larger user population. To further utilize the experiential dimension ask yourself questions such as these: Are there ways that this vocational activity can become recreational? Are there ways that recreational activities can become vocational? This technique will cause you to redefine the problem or problems over and over until the need has been properly identified.

DIMENSION TWO - INGREDIENTS OF BALANCE IN A BEING

THE BODY

'Body' shall refer to the physical aspects of life. The 'body' is capable of performing many physical tasks such as eating, drinking, sleeping etc. A 'body' by itself is virtually incapable of sustaining itself without the intellect and spirit to provide guidance.

Rehabilitation centers justifiably place an emphasis on the body. Many centers do an excellent job of caring for the physical body as a 'whole'. As a result of priority setting rehabilitation personnel tend to overlook the 'whole being'. Unfortunately this means that there is less emphasis on the mind and spirit. As a result, professional problem solvers end up designing devices and systems that perform the task at the expense of esthetics, practicality and other design criteria important to the user.

THE MIND

'Mind' shall refer to the intellectual aspects of life. Among these are reasoning, logic and imagination which provide the body with the instructions, direction and coordination necessary to maintain bodily functions.

The teaching of skills to cope with a disability is one manifestation of the intellectual approach to rehabilitation. The aquisition of further knowledge and understanding of one's disability is another important intellectual part of a rehabilitation program.

Rehabilitation professionals tend to be very bodily and intellectually oriented. These professionals are the people directing most rehabilitation efforts. Too much emphasis on the intellectual approach without including the development of the physical body can create an imbalance. Furthermore, one should remember that the intellectual properties of man or woman can not manifest themselves without a physical body in which to reside. It is therefore important to balance the rehabilitation effort between 'body' and 'mind'.

THE SPIRIT

'Spirit' shall be defined as that which provides man's motivation and purpose in life. Without spirit man is not able to justify existance and propagation of his/her species.

Body and intellect are capable of existing without spiritual input for short periods of time. And the spirit by itself is capable of very great accomplishments even with very little bodily function. However, human beings have difficulty in living the experiential aspects of life without continued identification of purpose in their lives.

Rehabilitation efforts typically do not deal with the spiritual adjustment and adaptation required as a result of disability. The rehabilitation psychologist often provides the person whom is disabled with ways of coping with the physical disability only.

BALANCE

Each being has a balance between body mind and spirit that is different from the next person's balance. Balance does not imply that body, mind and spirit are equal in magnitude, strength and importance. Balance does imply that body, mind and spirit are each of appropriate magnitude for a given individual being's makeup. Examples of two different people might look like:

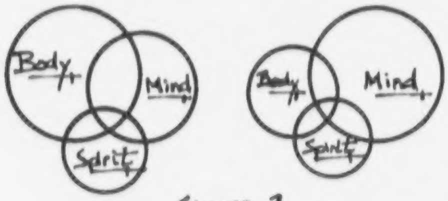


Figure 2

Rehabilitation tends to place an emphasis on the body. Rehabilitation tends to place less emphasis on the mind and the spirit. Rehabilitation programs pride themselves on caring for the whole body. Many of them do a very good job of taking care of all of the parts of the body. Rehabilitation programs should be aimed at rehabilitating the whole being, not just the whole body.

INTERACTION

Body, mind and spirit are not three independent entities that can be discussed by themselves. An interactive and interelated symmetry is necessary for the body, the mind, and the spirit to survive. The degree of interaction between an individuals body mind and spirit is not the same for everyone. Graphic visualizations of two different people might look like this:

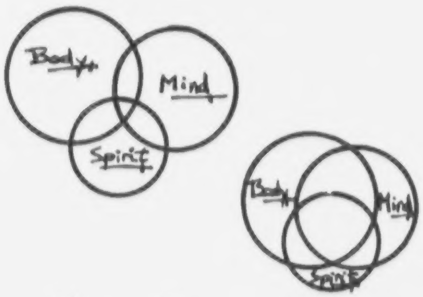


Figure 3

In the lower visualization the body, mind and spirit are very interrelated. During the execution of a physical task by such an individual the intellect and spirit of their being is present.

Some rehabilitation problem solvers have the breadth of experience and personal background to maintain balance of their own bodies, minds and spirits. Most problem solvers are professionals in "lineland." Professionals should be encouraged to venture out of "lineland" themselves. This can be done by exploring the minds and spirits of your patients, your friends and your collegues, as well as your own mind and spirit.

DIMENSION THREE SOCIOLOGICAL

DEPENDENCE

Dependence is a concept that many people can not live with and other people can not live without. Dependence can mean security for one person and insecurity for another.

Dependence on devices, systems and other people is often a reality for persons with disabilities. However, people desire choices and options. The person who has a choice between dependence and independence and chooses dependence will have a different attitude than the person who is not given a choice.

Many devices for persons with disabilities are dependent on able-bodied attendants. Devices sometimes facilitate independence from other people but increase the dependence on devices. Other people desire independence from devices and prefer being dependent on other people.

INDEPENDENCE

Independence is a concept which usually describes a person's attitude toward the environment around them. When someone is in control of a situation or their environment they are usually viewed as being independent. A contradiction exists in that the person, in their independence, is usually controlling the environment or the situation by utilizing devices, systems or people. There is great security in being in control of any situation. At the same time the potential for insecurity is great since no one fully controls their environment all of the time. Furthermore there is often an overemphasis on independence in the rehabilitation environment.

INTERDEPENDENCE

In the sociological dimension somewhere between dependence and independence lies an acceptance of social integration that transcends the limitations of a dependent or independent lifestyle. The person living an interdependent lifestyle must have the strength and courage to stand up for his or her convictions and be able to accept fault and support at the same time. The ability to know when to lead and when to listen is the most difficult aspect of being an interdependent person.

The sociological dimension suggests a clean line along which various degrees of interdependence exist with total dependence and independence at the extreemes. As a 'humanistic designer' you should determine where you, as a problem solver, lie along this dimension. Are you an independent or a dependent person? Your abilities to define a problem will be restricted by your inability to be a dependent, independent and interdependent person all at the same time. If you are an independent person, try experiencing the lifestyle of a quadriplegic wheelchair user by using an electric wheelchair for a day. If you are a dependent person try working alone at something for a day without using any electrical or mechanical devices.

CONCLUSION

As a humanistic designer solving problems for persons with disabilities you will be faced with many overwhelming problems. When you are initially trying to determine the needs of a user population examine first your own position within the spatial dimensions discussed in this paper. Are you an independent or a dependent person? Are your spiritual priorities above your intellectual and physical priorities? Do you value your vocational outlets above recreation? Pinpoint where your personality priorities place you within the experiential, sociological and the human balance dimensions. Explore and experience other priorities within the dimensions. Think about the problems you perceive as you experience other aspects of the three dimensions discussed.

Now think about the needs of the persons with disabilities for whom you are trying to identify problems. Where do the personalities and priorities of these people lie within each of the dimensions discussed. Are there perhaps users of a potential device or system you are forgetting about? Interact with these people. Question users, work with them, play with them, recreate with them, experience life's activities with them and give them something back in exchange for their time; hopefully you will both gain from the experience.

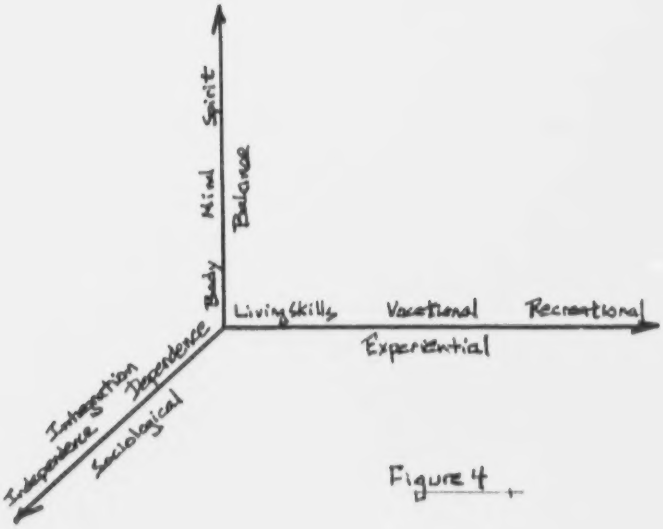


Figure 4

BENFICIAL DESIGNS INC.
5858 Empire Grade Road
Santa Cruz, CA 95060
(408) 425-5098

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[1] Edwin A. Abbott, Flatland (Dover Publications, Inc. New York, 1952).

OUR IMPRISONMENT OF THE HANDICAPPED: A BRITISH PERSPECTIVE

Dr. G. T. Hamilton, M.B., B.S., D.R.C.O.G.,
St. John's Health Centre, Woking, Surrey, England.

ABSTRACT

Current solutions to many problems of the handicapped profoundly affecting the quality of their everyday living, are largely dictated by unhandicapped people. This applies to the design and assisted supply of commonly used aids as well as financial provision for their general welfare and adaption of the environment for their special needs. Government agencies, industrial companies and charitable organisations have the greatest involvement in these respects. Government agencies (usually poorly coordinated) are subject to the vagaries of shifting political ideologies dependent on the party currently in power and its attitude to budgetary generosity, or lack of it; industrial companies operate on normal commercial principles, so that selling to a largely non-wage earning market immediately puts them at a striking disadvantage. Charities are in the impossible dilemma of advancing the causes of diversely disabled clients whilst simultaneously giving as little offence as possible to the Government, whose real responsibility such clients are: moreover as the most influential members of many charities are past their first flush of youth, conservative attitudes and a disinclination to alter the status quo can easily prevail.

Research is needed to find out what the Handicapped themselves really want in all respects of their lives. A project proposal for such research has been submitted in Britain and cooperation is sought for a similar U.S. project dealing with Handicap aids. These do not reflect recent advances in technology of all kinds and however well meant, often restrict the horizons of their users. More emphasis should be placed on adapting the Handicapped to the world and less on adapting the world for the handicapped. Knowledge gained from such research should be used to influence Government agencies and manufacturers of aids so that available resources can be used to their best effect.

BACKGROUND

I am in general practice in England. In 1977 I attended a dysphasic stroke victim who had fallen from his wheelchair to a thickly carpeted floor. For a variety of reasons it was not until 5 days after this accident that I realised he had sustained a fractured femur. My failure to diagnose this immediately made little difference to his quality of life, but it did bring home to me the extent of his plight and his grossly restricted horizons. As a result of this experience I had the idea for a communication aid - SPLINK - and was very fortunate in being allowed by eventual commercial manufacturers of the device to play a large part in its evolution: my work chiefly was a rather crude form of market research with relatives of potential users and therapists, along with the choice of words for the word board and the best way to display them.

The selection of words for the word board was achieved with the active participation of handicapped and housebound people and their relatives and attendants. It was found that a difference of about 10% - nearly 100 words - existed when their perceived necessary words were compared with a composite word frequency source compiled from unhandicapped people. These different words were all related to their immediate restricted surroundings and bodily comforts including items of food and drink and a rather sombre and low key collection of depressive adjectives and nouns presumably resulting from their deprived status. When the final selection had been made many linguistic experts were consulted for advice on their optimum arrangement and many ingenious methods suggested. It was finally decided to display them alphabetically on the basis that the greatest number of potential users would find this the simplest method to understand and use. It was also decided to display the letters of the alphabet (needed for spelling words not included on the board) in such a way to encourage maximal use of the available words and discourage the spelling out of others. This was an excellent example of unhandicapped people making assumptions on behalf of the handicapped; although, theoretically learning the available words and using them as much as possible leads to more rapid communication it can in many cases become extremely boring, frustrating and unnecessarily restricting. In mitigation we can plead that the actual researching of such evidently recondite factors with people who are unable to speak does present formidable problems!

Three prototype devices were then constructed by the Electronics Department of Bristol University for clinical trials. A speech pathologist, Pam Enderby joined the project prior to their arrival, and designed the format for the trials. It was only then that we realised that formal clinical trials had not previously been carried out on any communication aid; this put an immediate restriction on the nature and completeness of our trial and severely limited the comparisons which could be made. It is interesting that, as a practicing Doctor, it had never occurred to me that any aid could be introduced commercially without properly designed trials. I would not use any drug which had not been so tested, nor commend to any patient of mine a surgical procedure which has not emerged as the best suited for their particular affliction.

An initial Trial[1] was carried out by Pam Enderby in the Bristol area in 1978-1979, using the three prototype SPLINKS.

This Clinical Trial of SPLINK was designed to:

1. Gauge its usefulness
    - as a sole communicator,
    - as an aid to communication and
    - as a teaching aid
2. Establish the aid's acceptability
    - to patient,
    - family,
    - staff and
    - public
3. To investigate its practicality,
    - reliability,
    - durability and
    - versatility
4. Define the capability of different groups of patients to use SPLINK.

The initial trial was conducted in the homes of 20 profoundly speech-handicapped in Bristol, each of whom had a device for at least 2 weeks, with comparative assessments made initially and finally. As a result, quite significant changes in design for the second, multi-centre trial, were made. These included a 25% reduction in size of the word board, printing of the words and letters in a clearer type and in lower rather than upper case, and an infra-red transmission facility which did away with the necessity for a trailing cable from the word board. Such modifications were very important and would not have evolved had the initial trial not taken place. 16 of the 20 users in this initial trial benefitted significantly from the use of SPLINK.

The success of the initial trial prompted over optimistic commercial assessments as to the size of the market in terms of the number of devices which actually would be sold. Many factors standing in the way of hard sales were not appreciated, and enthusiasm for the device was confused with commercial viability. Forty modified units were made by the manufacturers and were used for a second, multi-centre trial in the U.K. and U.S.A. Aims in this trial were similar to those already described, but more information was sought from the therapists, teachers and relatives of the users. The trial was far more broadly based both geographically and in terms of the age range and aetiology of disability. Positive (i.e. favourable) results emerged from over half the users, which seemed to demonstrate that a substantial proportion of speech-handicapped in both countries would benefit from using SPLINK in a number of ways and that in the case of some users it could enormously improve the quality of life.

I am now engaged in the design and development of an aid for physically handicapped people, primarily victims of paraplegia. It is hoped that such people will be able to ascend and descend most staircases independently by its use. When and if a prototype stage is reached, clinical trials will take place in the U.K. and U.S.A.

PROPOSAL

Proposal for a Research Project into Aids for physical handicap in the U.K. and overseas, specifically excluding blindness, deafness and speech-handicap.

Twenty years experience in General Practice, five years of more extensive contact with the handicapped of all ages and their families, and participation in Conferences and Exhibitions devoted to them and their problems have left the following predominant impressions.

i) Many commonly-used Aids only function in limited situations and with the help of an able-bodied person, restricting both the environment and independence of the handicapped user (and, for that matter, the third party). Lip service is paid to the concept of adapting the world for the convenience of the handicapped, but this happens haphazardly and to a totally inadequate extent. Too many handicapped a imprisoned, effectively living out their lives in a few crudely adapted rooms. Whilst for some severely handicapped this may be the only current solution to their problems, the same is not true of the less severely handicapped, and this distinction is rarely either understood or applied. Going on holiday for a handicapped person too often means staying in an institution (even if graced by the name of an hotel), specially adapted for their needs, surrounded by other handicapped people and perforce cared for by their nearest and dearest, who may be badly in need of a genuine break. All of these factors increase the feelings the handicapped already have in painful measure of being "different" from the rest of humanity, and ensure their increasing isolation from the society of unhandicapped people.

ii) These commonly used Aids are duplicated massively by Manufacturers. This implies a waste of resources, there usually being few striking differences in items designed for a common purpose by several manufacturers.

iii) Much equipment is designed by the unhandicapped people with little consultation with intended users, at least until it is in production when, at best, modifications may be made to what may already be inappropriate devices.

iv) Formulation of needs and Aids for the handicapped by various Authorities tends to be unambitious, mundane, rigid and far too infrequently subject to rivision. The spectacular advances in technology of the past twenty years are staggeringly disproportionate to their frugal uptake by designers of Aids. As a result the handicapped may be resentful and hopeless, feeling that too little is done for them, and usually by people who seem to have little understanding of their real needs; on the other hand some seem pathetically grateful for what, to any perspective observer, is a pitifully small response to their needs.

This is aided and abetted by:

v) The constant unremitting struggle the handicapped and those caring for them have in evolving as simple as possible a routine for daily living: their strength is further drained by frequent brushes with what often appears to them a grudging, ill-attuned and parsimonious bureaucracy. This adverse combination results in a majority of disabled people being compliant and undemanding so far as the provision of Aids is concerned.

vi) Some handicapped actively resist the use of Aids, and frequently receive encouragement in their resistance from relatives, friends, Professionals and Charitable bodies. In this context, Aids - pre-eminently wheel-chairs but also sticks and walking frames - are seen as a last resort. A handicapped person often will declare that he or she can manage perfectly well without a suggested Aid; enquiry reveals restricted and contracted horizons passively accepted as a consequence of the particular disability. A prime example of this is young victims of severe multiple sclerosis who refuse wheel-chairs despite the fact that these enable them to participate in shopping and attend social and sporting occasions. The denial of these activities results in a permanently housebound situation, and it is sad to reflect that this has often been unwittingly aided by either the inaction or the wrongful motivation of Professionals whose purpose is to make life richer and not poorer in quality for their clients.

The general end result of all this is that the "Handicapped" and "Disabled" are in the eyes of society at large a homogeneous group of ill-understood and rather embarassing departures from the norm. Many people, whilst feeling sorry for them and contributing readily but inadequately, to their Flag days, inwardly prefer to encounter them as little as possible, imagining that they are well cared for by "them" - i.e. the N.H.S.* Nothing could be further from the truth.

vii) Just as unhandicapped like to spend their earnings on attractive and well designed products, so the handicapped prefer their Aids to be visually appealing to them and others, as well as fulfilling their function as positively and discreetly as possible. Just as our knowledge of the psychology of the handicapped themselves is sadly lacking, so it is when applied to their Aids.

Any one person's efforts can only have a limited impact on the problems outlined. I would like to propose a project which would have as its main aims:

a) A critical appraisal of currently available Aids as seen through the eyes of their users and intended users.

b) An elucidation of ways in which handicapped people feel they would like their horizons broadened with the assistance of Aids, given an absence of financial and technological constraint.

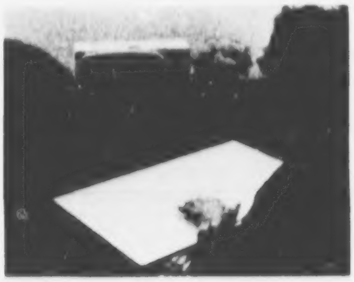
c) The encouragement of research along these lines in overseas countries, notably in North America and Europe, once the pilot project has been set up in the U.K.

d) As a result of such research, the setting up of groups, internationally to use the findings to influence Manufacturers in the development of new horizon-broadening Aids and Government in their attitudes and resource allocation to handicapped populations.

My contribution to this would be a U.K. study of between 100 and 300 handicapped in three age groups, 0-16; 16-60; and 60 onwards. Such a study would be set up with expert methodical advice and would gather and collate the following data:

What Aids are currently used?
How were they obtained?
How easy were they to obtain?
How easily were funds provided by outside sources?
How reliable are they and what faults are prone to develop?
If a fault develops how easily and quickly can it be put right by the family or the manufacturer?
What anomalies in this data are perceived by them?
What activities and functions now denied them would they like to be provided for by and Aid or Aids?
Have they any personal ideas as to how particular Aids should be designed and developed?

SPLINK



1 Int. J. Rehab. Research, 1981, 4(2), 181-195

Any interested U.S. participant, please write, airmail, to me at:

The Health Centre,
St. John's,
Woking,
Surrey,
ENGLAND.

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* National Health Service.

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9.7

ENVIRONMENTAL CONTROL FOR COMMUNICATION AID/COMPUTER USERS

Philip Romich
Neil Russell

Prentke Romich Company

INTRODUCTION

As a result of severe physical impairment, many people are unable to perform tasks normally suited to able-bodied people. When operation of electrical devices is desired, frequently the device or the method of operation can be adapted to fit the capabilities of the physically handicapped. An environmental control unit permits the severely handicapped individual to control electrical devices in the home, hospital or work setting without assistance. Telephone, lights, electric bed, television, intercom, call signal, for example, may be operated independently. The objective of the ECU is to use technology to facilitate the operator's control over the environment, to promote independence and to improve the quality of life.

Presently, the primary ECU user group is high level spinal cord injured quadriplegics and the systems have been designed to accommodate their capabilities and needs. The general approach for control has been two switch operation: one to select the function to be performed, the other to operate that function.

There is a growing need for environmental control from another population. Those persons who are users of expressive communication aids or computers usually have the capability to generate serial data. The CONTROL 1 environmental control unit has been designed to utilize this ability.

The CONTROL 1 environmental control unit has been developed by Prentke Romich Company. The design of the CONTROL 1 was greatly influenced by the increasing use of devices capable of serial data output. Serial data output is a standard feature of many communication aids such as the Autocom and Express series. Most stationary and portable computers, the prospective aids of the future, also provide a serial output. The EPSON HX-20 and Panasonic Hand Held Computer exemplify this trend. The CONTROL 1 accepts coded serial data as an input and directly responds with telephone, lamp, appliance, electric bed, and other possible functions. This mode of operation is referred to as an ASCII DIRECT MODF. (ASCII is the abbreviation for American Standard Code for Information Interchange, the common serial data format.) The ASCII DIRECT MODE combined with a wireless serial data link enables remote operation for increased user mobility. TWO SWITCH SCANNING operation, which is typical of other environmental control units such as the Prentke Romich ECU 1, 2 and 3 is also possible with the CONTROL 1. These features should provide a versatile environmental control system compatible with present and future electronic aids and computers.

BACKGROUND AND METHODS

In determining the function of a new device an appropriate medium has to be sought between the two main goals of low cost and high function. Most environmental control units are designed in a component approach to give the user the option of purchasing additional present or future functions. The user therefore only has to pay for the functions wanted. This approach, however increases the overall cost of environmental control systems. The higher cost is mainly due to the increased packaging and interconnection hardware necessary for each component. The two extremes are therefore either a system with optional components for each function or a system which provides all possible functions in one package. A unit which provides all possible functions in one package would of course have a high cost and low flexibility. With these extremes in mind, one can see why the different models of ECUs exist on the market today. This logic may seem fundamental, but it is a major criterion in establishing a functional definition for any proposed device.

Environmental control systems have been available long enough to establish a history of popular configurations. When the history of modular systems was examined it was found that the telephone and bed control functions are usually purchased even though they are optional. This indicated that any new system should be designed with a special awareness of the expense in these areas.

The CONTROL 1 is designed to reduce the cost of the telephone and bed control functions and yet maintain flexibility. The telephone functions are operative when the CONTROL 1 is used with two standard commercial telephones. A telephone must be plugged into the PHONE connector and the telephone line must be plugged into the PHONE LINE connector. This telephone could be a speaker phone or a standard phone with the handset fastened to a gooseneck for positioning. A second telephone must be connected to the phone line to ring for incoming calls. This should not be considered an inconvenience because modern commercial telephones and "Y" adapters are inexpensive and a standard telephone should be located nearby in any case for manual use.

The major components for electric bed operation are also built in. An optional bed cable is all that is necessary for electric bed control. Electric bed manufacturers employ a variety of connectors and wiring configurations in their designs. This means that the bed cable to be used with CONTROL 1 must be specific to the user's own make and model of electric bed.

This brief discussion on the hardware aspects of the telephone and bed control functions is, of course, just a small portion of the total engineering process involved with microprocessor-based devices such as the CONTROL 1. When the overall hardware and software is considered a discussion of the engineering obviously exceeds the scope of this paper.

OPERATION

The CONTROL 1 may be operated in either a TWO SWITCH SCANNING MODE or an ASCII DIRECT MODE.

Operation in the TWO SWITCH SCANNING MODE requires that the user be able to operate a dual control switch such as a Rocking Lever, Tongue or Pneumatic (puff-sip) CONTROL INTERFACE.

Operation in the ASCII DIRECT MODE is possible if the user employs a device which outputs ASCII data such as an EXPRESS, an AUTOCOM, a terminal or computer.

The user may alternate between the modes. For example the user may employ the ASCII DIRECT MODE at a work station, but when in bed the user could perform control via a TWO SWITCH CONTROL INTERFACE.

In either mode the CONTROL 1 allows its user functional independence in the following areas:

* All aspects of telephone management including dialing out and receiving. Includes storage and automatic dialing of up to 10 thirteen (13) digit telephone numbers. Power failure operation is available with optional battery pack.

* Wireless operation of 120 volt lamps or appliances via BSR modules. The lamps may be dimmed or brightened as desired.

* Electric bed operation with an optional adapter cable.

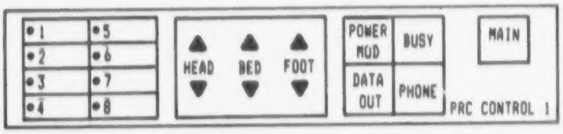
* Operation of various accessories which may be used in conjunction with the eight (8) control receptacles on the CONTROL 1. Each control receptacle provides both a contact closure and switched 12 volts DC. Some examples of available accessories are:

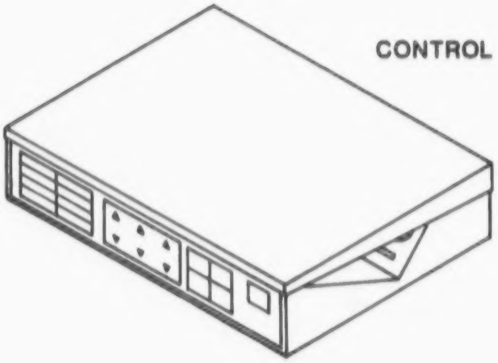
Television Channel Selectors
Intercoms
Call Signals
Power Draperies
Electric Door Openers
Custom Accessories

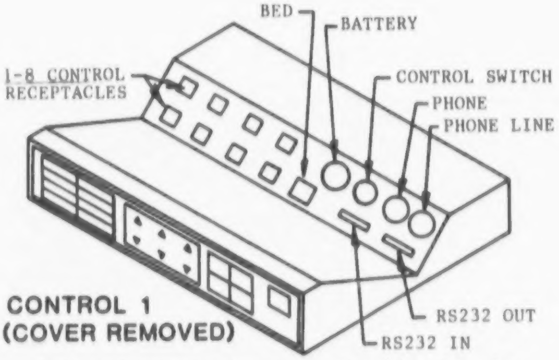
Enclosure

The CONTROL 1 enclosure is designed for pleasing appearance and ease of set up. A top cover provides access to the interconnection panel so that the various connectors can be concealed. The cables from the interconnection panel can then be routed out the rear or either side of the unit. The front panel has only discrete indicators for operational feedback of some functions. These indicators are:

MAIN - indicates that the power cord is connected to operating line voltage.
PHONE - lighted when the phone is off hook.
POWER MODULES - lighted while the ECU sends commands to BSR modules.
HEAD, BED, FOOT - indicates the section and direction of electric bed activation.
BUSY - lighted while the ECU is performing functions and cannot accept control inputs.
DATA OUT - lighted when the RS-232 serial data output is enabled.
1-8 - indicates status of control receptacles.




CONTROL 1



CONTROL 1 (COVER REMOVED)

The interconnection panel provides for the following connections:

PHONE - for connecting standard telephone or speaker phone
PHONE LINE - for connection to the telephone line
1-8 - eight control receptacles
BATTERY - for connection to optional battery pack to provide telephone operation during a power failure
BED - for optional electric bed cable
CONTROL SWITCH - for dual control switch when used in TWO SWITCH SCANNING
RS-232 IN - serial data in for use in ASCII DIRECT MODE
RS-232 OUT - serial data out

ASCII direct mode

When operating in the ASCII DIRECT MODE the CONTROL 1 responds to ASCII data commands received via the RS-232 input connector. The ASCII data commands can be sent via an Express, Autocom or other aids or computers capable of ASCII output. The user may also wish to employ remote control for greater independence.

The CONTROL 1 can output all the ASCII data that is received in the RS-232 input. Also, the CONTROL 1 responds only to specially coded commands. This means that the ASCII output may be used for data entry to a computer without accidentally performing ECU functions. The user can also turn off the ASCII output. Therefore, the functions of the CONTROL 1 may be performed with a minimum of computer work interruption. The ASCII data is "forwarded" via the RS-232 connector.

Two switch scanning mode

When a DUAL CONTROL SWITCH INTERFACE is used with the CONTROL 1 one side of the switch is used to select the function to be performed and the other side is used to operate that function. To know which function is selected a visual feedback display is desirable. This visual feedback display can be any alphanumeric display which has an RS-232 input such as a terminal. The visual input display connects to the RS-232 OUTPUT of the CONTROL 1. One option is a gooseneck mounted single line LCD display.

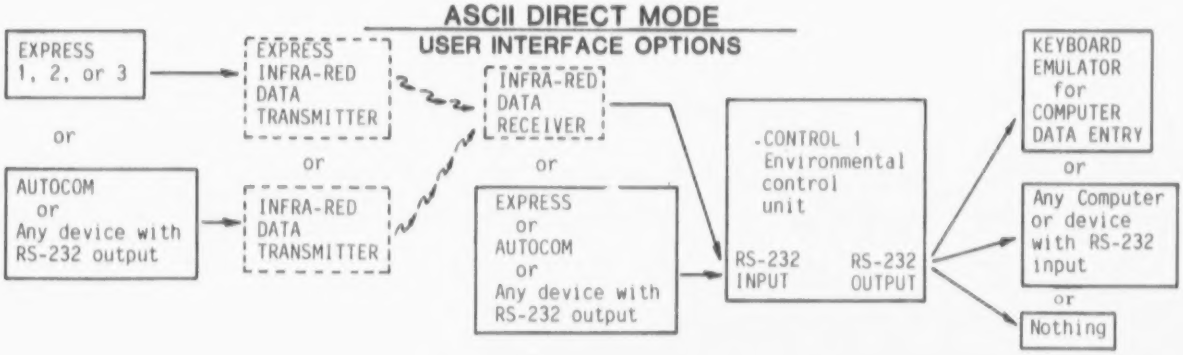
In operation the user selects the desired function by scanning through the menu of available functions. This scanning of the menu is accomplished by activating the SELECT side of the control switch. If the switch activation is maintained then the functions will step through at a preset speed. The user may change this speed as desired. Once the desired function is selected then that function is operated with the ON/OFF side of the switch. Operation by means of audio cues, although more difficult to learn, provides for people with visual impairment and other difficulty in viewing the display, such as in bed after being turned.

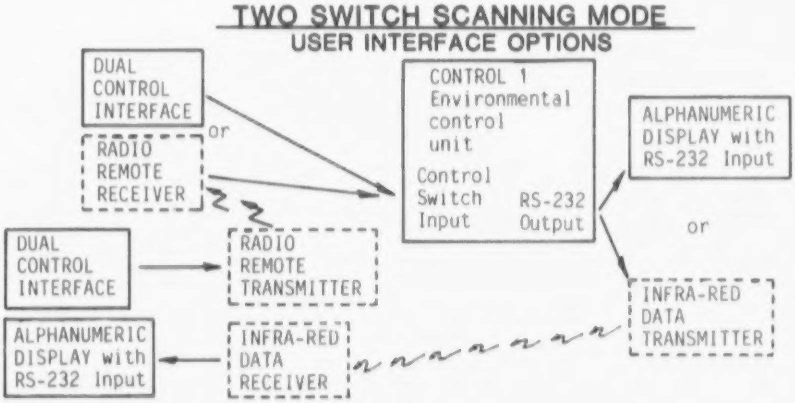
User interface options. Shown in the two block diagrams below are some user interface options. Components for remote operation are enclosed with broken borders. Note that in the TWO SWITCH SCANNING MODE the ALPHANUMERIC DISPLAY could perhaps be a hand held terminal or a hand held computer programmed to operate as a terminal. In the ASCII DIRECT MODE note that it is not necessary to have a device connected to the RS-232 output for operation. In this mode a small terminal or computer may be used for the INPUT device.

The CONTROL 1 will operate in which ever mode it senses that the user wishes to operate in. In other words if a switch closure is detected at the CONTROL SWITCH INPUT then it will operate in the TWO SWITCH SCANNING MODE. When serial data is detected at the RS-232 INPUT then it will operate in the ASCII DIRECT MODE.

Having studied the operating modes one can see that the TWO SWITCH SCANNING MODE can be used as a secondary mode for persons who operate (or plan to operate) the CONTROL 1 in the ASCII DIRECT MODE.

Philip Romich
Director of Research and Development
Prentke Romich Company
8769 Township Road 513
Shreve, Ohio 44676


ASCII DIRECT MODE
USER INTERFACE OPTIONS
EXPRESS 1, 2, or 3
or
AUTOCOM or Any device with RS-232 output
EXPRESS INFRA-RED DATA TRANSMITTER
or
INFRA-RED DATA TRANSMITTER
INFRA-RED DATA RECEIVER
or
EXPRESS or AUTOCOM or Any device with RS-232 output
CONTROL 1 Environmental control unit
RS-232 INPUT
RS-232 OUTPUT
KEYBOARD EMULATOR for COMPUTER DATA ENTRY
or
Any Computer or device with RS-232 input
or
Nothing


TWO SWITCH SCANNING MODE
USER INTERFACE OPTIONS
DUAL CONTROL INTERFACE
or
RADIO REMOTE RECEIVER
DUAL CONTROL INTERFACE
RADIO REMOTE TRANSMITTER
ALPHANUMERIC DISPLAY with RS-232 Input
INFRA-RED DATA RECEIVER
CONTROL 1 Environmental control unit
Control Switch Input
RS-232 Output
ALPHANUMERIC DISPLAY with RS-232 Input
or
INFRA-RED DATA TRANSMITTER

LAVOR -- A Low-cost APPLE-based Voiced Optical Reader

W. Teoh, M. Jansen and H. Gates
Indiana University-Purdue University At Fort Wayne
Fort Wayne, In 46805

INTRODUCTION

An optical reader having voice output capability is a very important tool for the visually impaired. Unfortunitely, most commercially available readers are very expensive. With the availability of low cost microcomputers, it is obvious that low cost systems based on these microcomputers could be designed. LAVOR (Low-cost APPLE-based Voiced Optical Reader) is such a system. The present prototype costs less than $4000 and is very reliable and easy to use. The end system (to be described later in this paper) should cost under $5000. This cost is sufficiently low to be within financial reach of many.

LAVOR SYSTEM

The present system is based on the popular APPLE II+ microcomputer. A 64K APPLE II+ computer (48 K RAM on the mother board and a 16K RAM Language Card) and one disk drive are required. The hardware organization is shown in Figure 1. In addition to the computer itself, an ECHO II voice synthesiser is used for the voice output. Video signals from the camera are digitized using a DITHERTIZER II board which is physically plugged into slot 7 of the APPLE motherboard. The digitized image may be placed on either page 1 or 2 of the high resolution screen.

In the prototype constructed, the camera is mounted vertically pointing downwards in a box, and the material to be read is placed flat on the bottom of the box. It is found that the digitized image is extremely sensitive to fluctuations of light intensities. Consequently, an adjustable light source is provided inside the box, which is otherwise shielded from ambient room light.

The software that controls the LAVOR system is considerably more complicated and is depicted in Figure 2. It is obvious that the software can be logically separated into two main portions AUTOGEN and IDEN16.

Early in the designing stage, it was decided that template matching technique will be used for character recognition. This technique is simple to implement, and is very flexible; by switching templates, the system can be used withour modification, to accomodate printed material in various fonts. The first portion of the software (AUTOGEN) concerns automatic template generation. Essentially, one places each alphabet under the camera and AUTOGEN invokes a routine called DSCAN to take a 'picture' of this character. A set of points (consisting of no more than 10 to 20 points) which uniquely identifies this character are generated and stored. When the entire set of alphabets (both upper and low cases) has been processed, AUTOGEN concatenates them, according to their letter frequencies, to form a master template for this particular font. This template is stored on disk and may be retrieved for letter identification. One such template must be made for each font, but this operation needs to be done only once. Since something like 10-15 common fonts are used for printing, this portion of the software is necessary.

Whereas AUTOGEN is used for automatic template generation, IDEN16 is used for letter identification. In this mode, the template is loaded into the computer memory, and the material to be read is placed under the camera. The digitized image is usually placed in page 2 of the high resolution screen of the APPLE. A routine called SEGMENT is then invoked to isolate each letter. At this point, the size of the character is also determined. Another routine called TEMPLATE SCALER is then invoked to scale the template to the same size as the screen characters. Each screen character is then compared with that in the template, provided that they both have very similar widths. All points in the template must be matched before a character is completely identified. Using vidicon tubes for image formation, situations could arise in which portions of a letter may be missing due to poor light conditions, print quality and other factors. Provisions have been made in the software to account for such occurances.

Figure 3 shows the memory map. The text-to-speech driver is that developed by P. Maggs and D. Visek, and is supplied with the ECHO II voice synthesiser. DSCAN which is responsible for digitizing the video images and places it on the high resolution screen, is suppled with the DITHERTIZER II board.

OPERATION AND FUTURE IMPROVEMENT

When properly adjusted, operating LAVOR involves simply placing the printed material at the bottom of the box and pressing a key on the keyboard. Tests conducted to date have shown that the prototype works well. Different size characters can be read on the same page, as suitable scaling is automatically by the software. A maximum skew of 7 degrees is tolerated by the system. Perfect character allignment is desirable but not crucial -- an important feature since the end users may be totally blind.

A problem yet to be resolved is as follows: since a standard lens having a minimum focusing distance of 18 inches is used for the prototype, in order to obtain an acceptable image on the high resolution screen, fairly large letters (approximately 1 inch in height) must be used. In order for the system to read smaller prints, a close-up lens, preferably a flat-field macro lens, should be used. The field of vision of such a lens, however, is so small that the camera would see only a small portion of the page of printed material. Thus, it is necessary to incoporate some form of scanning arrangement (an X-Y table, for example) under computer control. Such implementation is rather trivial, as very little modification needs to be made to the software of the system, and work is progressing in this direction. The final system is likely to resemble a typical copying machine, as shown in Figure 4. The camera could be mounted on a carriage which, under computer control, could scan along a line and down a page. The use needs only to place the printed matter, face down, on the glass surface, and the system will proceed to read the entire page automatically. Provisions will be made to store the material thus read on diskette (as an option). In this manner, an extensive "Talking Library" could be established.

CONCLUSION

There is no question that a voiced optical reader is a very important tool for the visually impaired. A low cost system such as LAVOR can play a very important role in education. As pointed out earlier, a "Talking Library" is feasible and valuable, as diskettes can be easily duplicated. The low cost of the LAVOR system, together with its reliable performance, would mean wider acceptance. Last, but not the least, it must be pointed out that the present system, when used in conjunction with the "Talking Typewriter" developed by the authors (1) using essentially the same hardware, could enable a totally blind person to function in an office environment. This aspect should not be ignored.

ACKNOWLEDGEMENT

The hardware for the present work was provided by a grant from Street Electronics, Anaheim, California. Portions of this project were funded by a grant from Indiana University-Purdue University at Fort Wayne.

REFERENCE

1. W. Teoh and H. Gates -- Customized Software approach To Rehabilitation Engineering, Proceedings, 5th Annual Conference On Rehabilitation Engineering, Houston, Texas, 1982, page 39.

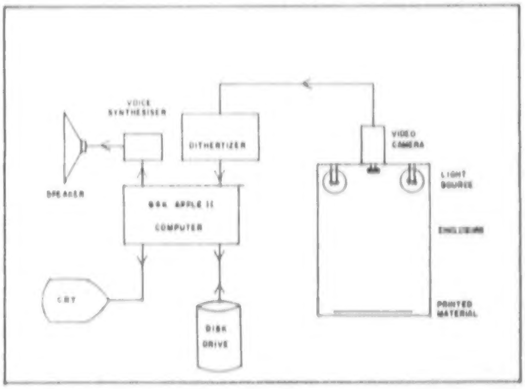

VOICE SYNTHESISER
DITHERTIZER
VIDEO CAMERA
LIGHT SOURCE
SPEAKER
64K APPLE II COMPUTER
ENCLOSURE
CRT
DISK DRIVE
PRINTED MATERIAL

Figure 1 -- Hardware organization

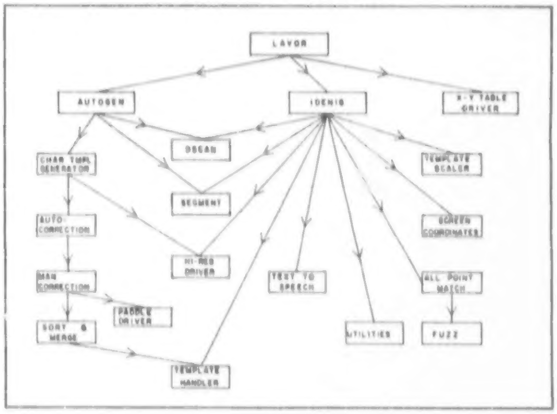

LAVOR
AUTOGEN
IDENIS
X-Y TABLE DRIVER
DSCAN
CHAR TMPL GENERATOR
TEMPLATE SCALER
SEGMENT
AUTO-CORRECTION
SCREEN COORDINATES
HI-RES DRIVER
TEXT TO SPEECH
ALL POINT MATCH
MAN CORRECTION
PADDLE DRIVER
SORT & MERGE
UTILITIES
FUZZ
TEMPLATE HANDLER

Figure 2 -- Software Organization

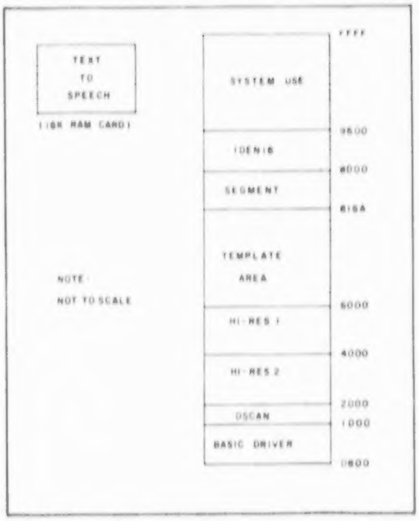

TEXT
TO
SPEECH
(16K RAM CARD)
NOTE:
NOT TO SCALE
SYSTEM USE
IDEN16
SEGMENT
TEMPLATE
AREA
HI-RES 1
HI-RES 2
DSCAN
BASIC DRIVER
FFFF
9600
9000
816A
6000
4000
2000
1000
0800

Figure 3 -- Memory usage map

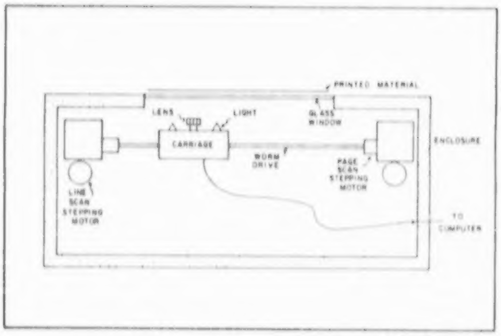

PRINTED MATERIAL
LENS
LIGHT
GLASS
WINDOW
CARRIAGE
ENCLOSURE
WORM
DRIVE
PAGE
SCAN
STEPPING
MOTOR
LINE
SCAN
STEPPING
MOTOR
TO
COMPUTER

Figure 4 -- Fully automated LAVOR system (under development)

W. Teoh
Kenneth Johnson Center,
University of Alabama at Huntsville,
Huntsville, Al 35899

H. Gates and M. Jansen
Dept. of Electrical Engineering Tech.,
Indiana Univ.-Purdue Univ. At Fort Wayne,
2101 Coliseum Blvd. East,
Fort Wayne, In 46805.

9.9

DEVELOPMENT OF TRAINING PROCEDURES FOR AN INTERACTIVE VOICE-CONTROLLED ROBOTIC AID

ROGER E. AWAD, K. G. ENGELHARDT, LARRY J. LEIFER, Ph.D
PALO ALTO VETERANS ADMINISTRATION MEDICAL CENTER
REHABILITATION RESEARCH AND DEVELOPMENT CENTER

ABSTRACT

Evaluation of medical robotics is a new field of research currently being conducted at the Palo Alto Veterans Administration Medical Center's Rehabilitation Research and Development Center. Training procedures and a users' manual have been developed to assist clinical evaluation of a voice controlled robotic aid. This paper discusses the process and types of training used by the Evaluation Team to assess the Human/Robot/Environment interface.

INTRODUCTION

Training is a critical component to acceptance of any advanced assistive device. Training has particular importance when computerized, interactive devices are involved. As Vaughn and Fryberger state, "essential ingredients to user acceptance of the system have been user involvement, user training..."1. "It is also necessary for adequate training to be implemented and persisted with if maximum usage is to result from provision of functional appliances."2.

It has been hypothesized that a robotic aid can increase control over the environment for high injury level quadriplegic persons. A voice-controlled rehabilitation robotic aid under development and evaluation at the Rehabilitation Research and Development Center, Palo Alto Veterans Administration Medical Center addresses the need for environmental control by individuals with high injury level spinal cord disabilities. A major aspect of the clinical evaluation of this device has been the development of training procedures for users. There are no established protocols for teaching individuals to use voice-controlled robotic aids. Development of training procedures has encompassed the following goals:

(a) development of successful user / machine profiles using training concepts based upon the Interactive Model of Evaluation developed by Engelhardt et al [1],

(b) better understanding of how training affects the process of learning to control the robotic aid,

(c) examination of the role of training in increasing the users' perception of control over the general environment,

(d) generation of data that will illuminate the barriers to user acceptance and technology dissemination,

(e) development of a training manual for users and trainers,

(f) evaluation of the training procedures and training biases.

BACKGROUND

The VA sponsored Stanford Robotic Aid Project began nearly two years ago and has included many professionals from many disciplines. It is the first system to incorporate a human-scale industrial manipulator (Unimation PUMA-250), a standard microprocessor-based, voice command unit, synthesized voice response, and a mixed mode hierarchial control software running in five independent microcomputers. The system has undergone clinical evaluation since October 1981.

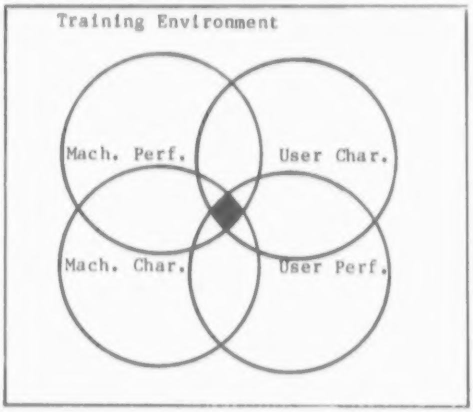
Development of training procedures began during the spring of 1982. The primary method for teaching individuals how to use the robot was verbal one-to-one communication prior to July 1982. A systematic development of training procedures commenced with renewed vigor in September 1982.

APPROACH

Training is the process of teaching the user to control the robotic aid in order to regain control over his/her personal space. Four factors interact during the training process to determine successful use of the robotic aid:

(1) Machine Characteristics
(2) Machine Performance
(3) User Characteristics
(4) User Performance.

These factors interact in a particular training environment accompanied by the consequent situational and training biases. Their relationship is best shown in the diagram below.



Training seeks to optimize the match among the four factors in order to achieve a successful user / machine interface. [See shaded area above.]

Machine characteristics under examination include: (a) operating modes: the robotic aid can be piloted in three different ways, (b) visual and verbal feedback to the user, (c) aesthetics such as size, appearance, sounds, and color, (d) the value of a general purpose device that enables the development of user specific tasks.

Machine performance is determined in the following ways: (a)tallying procedures have been developed to monitor the number and type of incorrect recognitions by the voice system, (b)records are also being maintained on safety and reliability of the robotic aid system (# of mechanical errors / failures).

The following user characteristics impact the training process: (a) limitations such as voice quality and physical stamina, (b) cognitive characteristics such as visual-spatial ability, attention span, workload, and intelligence, (c) motivation, (d) learning and achieving styles, (e) prior vocational experience and education, and (f) perceived locus of control (see discussion below). These characteristics will be assessed with questionnaires and recognized psychometric instruments, such as Rotter's I-E Scale and Norwicki & Strickland Locus of Control Scale.

Human performance will be assessed by the following: (a) ability to perform a designated task, (b) time required to complete a task, (c) the number of voice commands used for task completion, (d) demonstration of creative use of the robot. This last parameter might include the use of a unique sequence of commands not previously taught. User self-confidence and sense of control will be determined with questionnaires before, during, and after training.

The following parameters will be examined in evaluation of training procedures: (a) trainor characteristics and biases, (b) situational considerations such as time of day, (c) type of task(s) used in training.

Locus of Control

The Theory of Locus of Control has been used as a framework for examining how the training process affects learning to control the robotic aid. This theory is appropriate because disabled people are usually burdened with both real and perceived loss of control of their environment and often their lives. The goal of this study is to examine both their real and perceived sense of control using the robotic aid [3].

It has been hypothesized that the use of a general purpose assistive device, such as the robotic aid, can increase users' control over their personal environments. Studies using the Locus of Control theory have been designed to examine an individual's perceived control and to detect changes in that perception [3].

The Evaluation Team has also observed that there appears to be behavioral changes associated with the use of the robotic aid. Users' behaviors and verbalizations indicated that they were experiencing increased control. For instance, a 23 year old quadriplegic veteran commented, "Just think what I could do with three of them."

In order to investigate the effect of training on the user's sense of control of his/her environment and his/her actual skill in using the robotic aid, a group of twelve disabled persons will be trained to use the arm to perform common manipulation tasks. Two different training procedures will be used: (a)self-paced with a manual, and (b)trainer-paced with one-to-one instruction. Six users will be assigned to each procedure. Based on pilot tests which have been completed, our hypothesis is that differences in training procedures can be very significant in determining both a user's success in controlling the device and his/her psychological relationship to it. Our goal is not only to train users who are technically competent in using the robotic aid, but develop the user's general feeling of control over his/her environment. If training enhances the user's "real" sense of control, that is, if we produce technically competent users who choose to use the device to increase their personal independence, we will have reached one major goal. We will also assess any changes in the user's perceived sense of control after exposure and training with the robotic aid.

DISCUSSION AND CONCLUSIONS

Twelve quadriplegic persons and twenty non-disabled individuals have been trained to use the robotic aid system as part of the development of training procedures. Training has indicated successful user / machine profiles based upon the Interactive Model of Evaluation developed by Engelhardt et al[1].

A 75-page manual has been developed. It is designed for the user and the trainer. Appendices to the manual contain the technical information an interested engineer might desire.

Nearly all users, particularly quadriplegic users, expressed enthusiasm in learning to use the robotic aid. One quadriplegic graduate student, who was initially quite skeptical, concluded that the robotic aid has significant potential to make his life more independent. The users found the system 'friendly' and enjoyed working with the robot.

The advantages of a general purpose device were corroboratated by the many users who could imagine the robotic aid in their home settings. The most often desired tasks include: (a) obtaining a drink of water, (b) cooking and serving a meal, (c)self-feeding, (d) handling clothes and other personal belongings, and (e) vocational applications. All users learned to pick up a cup within one hour of their first introduction to the robotic aid system. Mobility for the robotic aid is also often mentioned as an essential quality if this device is to be practical. The users also expressed a desire for several robotic aids to assist them in their daily living.

Incorrect recognitions of the voice commands was the primary source of low-level user frustration. This occurence has prompted additional detailed evaluation of the voice commands. Testing of alternate commands (with different amplitude qualities) is being conducted at the present time.

ACKNOWLEDGEMENTS

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Inder Perkash, MD
Johnny Bowen
Tim Heritage
Andrew Batavia
Dean Wilken

FOOTNOTES

1. See Reference [4]
2. See Reference [2]

REFERENCES

[1] Engelhardt, K.G., *et al*, "Methodology of Preliminary Findings from the Evaluation of an Interactive Manipulation Aid", *Proceedings of the Fifth Annual Conference on Rehabilitation Engineering,* Houston, Texas, August, 1982, p.100.

[2] Gobel, R.E.A., Nichols, P.J.R., *Rehabilitation of the Severly Disabled,* Butterworths, London, England, 1971.

[3] Leftcourt, H.M., *Locus of Control: Current Trends in Theory and Research,* Lawrence Erlinbaum Associates, Hillsdale, N.J., 1976.

[4] Vaughn, P., *Developing an Online Interactive System for the Naive User,* University of Colorado, 1982.

Mailing Address:

R. E. Awad
Rehabilitation Research & Development
Center/153
Palo Alto VA Medical Center
3801 Miranda Avenue
Palo Alto, CA 94304

EVALUATION OF A ROBOTIC AID: FROM THEORY TO APPLICATION USING AN INTERACTIVE MODEL

9.10

K. G. ENGELHARDT, ROGER WICKE, Ph.D,
GREGORY L. GOODRICH, Ph.D, LARRY J. LEIFER, Ph.D
PALO ALTO VETERANS ADMINISTRATION MEDICAL CENTER
REHABILITATION RESEARCH AND DEVELOPMENT CENTER

ABSTRACT

There is a need for user-focused evaluation research on advanced assitive devices, particularly at the prototype stage. The government regulates safety and efficacy of market-ready products through the FDA, but has no standardized protocols for evaluation of prototypic or rehabilitation products. An applied evaluation model to facilitate users' and allied health professionals' input at all stages of the development process is needed to assure that the products generated are useful to the disabled. This paper discusses an Interactive Evaluation Model developed by a team of researchers at the Rehabilitation Research & Development Center. This dynamic model is being used as a tool to facilitate flexible, ongoing prototype evaluation and information flow.

INTRODUCTION

The need to involve users and multidisciplinary allied professionals in the research and evaluation of advanced assistive devices is critical. The Office of Technology Assessment's Report, Technology and Handicapped People, asks: "How can policies and programs be designed to encourage or assure the effective involvement of disabled people and other consumers in the development and delivery of technologies? In addition to providing information, consumers should themselves be part of advisory and policy-making bodies to the maximum extent feasible."[1]

Robert Radocy proposes that, "direct communication with individuals of the target population is an important source of information regarding their needs and problems and their opinions..." He maintains that, "although time-consuming and tedious, direct communication still provides the most reliable source of information to the product developer."[2]

The evolving RR&D Evaluation team is directly addressing this gap in rehabilitative engineering efforts. The Interactive Evaluation Model for prototypes has been designed to generate much needed information. Development of state-of-the-art devices for the disabled must include a steady flow of feedback to the designers and developers in order to decrease development time, upgrade devices, and make them acceptable end-products. User feedback can facilitate the development of end-products that are more appropriate to the user's needs.

BACKGROUND

The OTA Report (1982) concluded that: "Evaluation is -- or should be -- an ongoing and integral part of the entire lifecycle.... A coherent, and well-focused program of evaluation is necessary at all levels of technology diffusion and adoption. Such a program does not currently exist in the disability-related technology sector. Consumer involvement is one of the most talked about aspects of the disability-related policy area - and everyone seems to believe in the concept but few satisfactory schemes to improve the situation were suggested to OTA and few people or agencies appear to be taking aggressive steps to put the concept into practice."[3]

The dominant question is, "how can evaluation of present and emerging technologies be organized to provide consumers, providers, and policy-makers with adequate information?"[4] The Interactive Evaluation Model attempts to address this problem in a unique way.

The Model has proved an effective tool in evaluation of a general purpose robotic aid. By using the Interactive Evaluation Model developed by Engelhardt, et al.[2] and applying it to the clinical setting, the user/consumer is at the focus of the technologies being developed. The development of the robotic aid is targeted specifically to the quadriplegic population (even though it will eventually have much wider application); it is imperative that they become involved in developing the training procedures and help evaluate the components of the system.

Vaughn and Fryberger state: "Essential ingredients to user acceptance of the system have been user-involvement, user-training.... A system will not be accepted if it does not fill a need which the end-user recognizes as a need. In order to accomplish this, users were involved with all phases of the development and played a role during the external design phase. This allowed users to enhance their understanding of terminology, and made them more comfortable with the computer hardware. In addition, this provided valuable feedback to analysts about potential system problems. Analysts noticed that users began to get more interested and curious about features they wanted to have included in the finished system."[5]

User feedback is essential in the design of a device in order to assure user acceptability, which will be critical to its later diffusion as a market-ready product. Information from this interactive research and development will be used to establish a data base of information about SCI persons' characteristics, needs, and abilities.

It is hypothesized that user involvement during the early stages of development will increase acceptance and utility of the devices, and will produce well-engineered end-products that are more effective and appropriate.

METHODOLOGY

A Model of Evaluation

An interdisciplinary evaluation effort is imperative for investigation of the desirability and functional utility of advanced assistive devices. A team composed of individuals from a variety of disciplines has been organized at the RR&D Center to develop research protocols and a working model for prototype evaluation. The Interactive Evaluation model, developed by Engelhardt, *et al.*[2] is a tool to facilitate a flexible, ongoing evaluation process. Its primary objective is to provide user input and feedback to the developers of advanced assistive devices for the disabled.

The purpose of the model is the following: (a) develop baseline information on performance characteristics of the machine/human interface, (b) provide current feedback to designers and developers, (c) assess the applicability and acceptability of advanced assistive devices, (d) study pertinent psychosocial parameters, (e) generate data on a successful user and successful system profile, (f) determine the most effective user training procedures for each class of assistive devices.

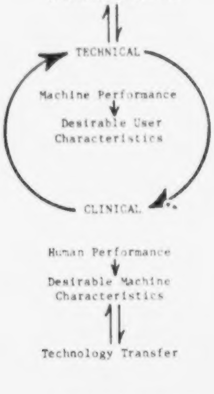
Evaluation Questions:

(a)Can an increased level of user input produce a more acceptable product?

(b)Can involvement of users and allied professionals help accelerate the development process?

(c)What is the best methodology to use in training a person to control and manipulate state-of-the-art assistive devices, such as a robotic aid?

The model calls for simultaneous investigation of both the machine's and the human's performance. It is hypothesized that this interactive focus will help determine desirable characteristics for both the user and the system. User-specific tasks have been designed that will challenge the system and the user. These tasks are defined by the user to suit his/her needs. The development and evaluation team will then work with the system and the user to see if the tasks can be accomplished and if not, why. The model is shown below.



The emphasis on simultaneous technical and clinical investigation will help engineers, designers, and evaluators better understand the desirable characteristics and performance parameters of both the human and the machine. This model allows the potential users to become interactive participants in the research that will focus on issues specific to their needs.

Control

A person's control of his/her personal space is an important component of human dignity and the quality of life. It has been hypothesized that the use of a general purpose assistive device, such as the robotic aid, can increase users' perceived and functional control over their environment. Control is an issue that is well-suited to both a clinical and technical examination of the Human/Robot/Environment interface.

Voice Input. Studies on voice activation of the robotic aid demonstrate how both clinical and technical data can be acquired using the Interactive Evaluation Model and focusing on the issue of control.

The Evaluation Team has been using a Voterm user-dependent speech recognition unit as the primary input device that allows control of the robotic arm. Evaluation of this command channel which gives the user control of the robotic system is being conducted. Various arm motions are initiated by specific spoken commands from a vocabulary of 57 words. For safety and ease of use, it is desirable that these commands be recognized with a high degree of accuracy and without frequent confusion with other commands. Several factors interact to influence the quality of recognition: the consistency with which each user repeats command words in training and in use, and the inherent capabilities of the device itself. The speech recognition device was evaluated with several goals in mind: 1) to determine the limitations of the device; 2) to improve the choice of vocabulary words in order to minimize confusion errors; and 3) to determine whether and how the user can be trained to improve voice consistency. Please see Figure 2.

Psychosocial Aspects of Control. Jim Tobias states that devices, generally speaking, offer *control* which he maintains is a "psychological entity" because "we are replacing *inabilities* with *abilities*, and their physical manifestations, important as they are, may be accompanied by vast psychological transfromations."6 Tobias used the Locus of Control Theory to examine the psycho-psychological impact of devices after noting that patients appeared to be more socially active after using appropriate mobility aids [6].

The evaluation team at the RR&D Center has designed a companion study to address the concept of control from a psychosocial perspective. The Locus of Control Study focuses on quantifiable psychosocial aspects of perceived control. Studies using the Locus of Control theory have been designed to examine an individual's perceived control and to detect changes in that perception [3]. We are focusing on the Locus of Control theory because disabled people are usually burdened with both real and perceived loss of control of their environment and often their lives. It is our goal to examine both their real and perceived sense of control using a general purpose assistive device.

DISCUSSION AND CONCLUSIONS

"More than ever before, technology is bridging the gap between physical disabilities and the limitations those disabilities impose -- allowing disabled people to become more independent.[7] New fields of research and development of advanced assistive devices are being explored daily. Yet, while the development continues, the end user is often ignored. This can lead to products that are inappropriate for the designated target population, and acceptance and utilization rates can be affected. We hypothesize that interactive prototype evaluation can significantly improve the long-range efficiency and value of the rehabilitation R&D process. User-focused evaluation efforts will lead to a better allocation of scarce resources and more appropriate end-products. The major goals of the Interactive Evaluation Model are to determine both the user and system characteristics that affect performance, acceptance, and utility, and to provide current user and allied professional feedback to the development team so that design changes can be initiated in the laboratory development system.

This model has been an effective tool in examining various interfaces in the Human/Robot/Environment triad. In the future, this user-focused Model will be utilized to acquire evaluation information on other classes of advanced assistive devices.

FOOTNOTES

1. See Reference [4]
2. See Reference [5]
3. See Reference [4]
4. See Reference [4]
5. See Reference [7]
6. See Reference [6]
7. See Reference [1]

Author's address:

K. G. Engelhardt, Evaluation Supervisor
Rehabilitation Research and Development Center/153
Veterans Administration Medical Center
3801 Miranda Avenue
Palo Alto, CA 94304

Figure 2

INTERACTIVE EVALUATION

Continued Research

TECHNICAL DEVELOPMENT

Machine Performance:
- ability to recognize utterances of a word which differ in:
  pitch, loudness, phonation,
  inflection, speed;
- quality (raspiness, breathiness, etc.);
- position of microphone during utterance.

Desirable User Characteristics:
- determines the regularity which the user must maintain in:
  pitch, loudness,
  inflection, speed,
  microphone position;
- determines the limitations of the system with respect to phonation disorders.

CLINICAL TESTS

Human Performance:
- limitations of ability to repeat words consistently,
- range of voice quality

Desirable Machine Characteristics:
- vocabulary changes,
- possible modifications in machine design.

TECHNOLOGY TRANSFER

Demographics of potential users

Determining possible alterations of the system to accommodate specific subpopulations of disabled users.

REFERENCES

[1] Baker, R., "Technology for the Uninitiated", *Disability: The College's Challenge*, 1981.

[2] Engelhardt, K. G., *et al*, "Methodology of Preliminary Findings from the Evaluation of an Interactive Manipulation Aid", *Proceedings of the Fifth Annual Conference on Rehabilitation Engineering*, Houston, Texas, August 1982, p.100.

[3] Leftcourt, H.M., *Locus of Control: Current Trends in Theory and Research*, Lawrence Erlibaum Associates, Hillsdale, N.J., 1976.

[4] Office of Technology Assessment, U.S. Congress, *Technology and Handicapped People*, U.S. G.P.O., Washington D.C., May 1982.

[5] Radocy, R., "Strategies for Developing and Marketing Products for Special Populations", *Technology for Independent Living*, Project on the Handicapped In Science, AAAS, Washington D.C., 1982, p. 167.

[6] Tobias, J., "A Psychological Issue in Rehabilitation Engineering", *Proceedings of the Fifth Annual Conference on Rehabilitation Engineering*, Houston, Texas, August 1982, p.17.

[7] Vaughn, P., Fryberger, R., *Developing an Online Interactive System for the Naive User*, University of Colorado, 1982.

9.11 PRESSURE RELIEF CHARACTERISTICS OF SIX THERAPEUTIC MATTRESS SURFACES

Irena Herszkowicz, MOTR, The Institute for Rehab. & Research
Thomas Krouskop, Ph.D., Baylor College of Medicine
Susan Garber, OTR, Baylor College of Medicine
Rebecca Williams, M.Eng., Baylor College of Medicine

INTRODUCTION

Pressure and shear induced soft tissue breakdown is a major concern for the rehabilitation team. Skin breakdown can be life threatening, especially for individuals with absent or diminished sensation or lack of mobility.(1) Preventive measures may be taken through the prescription of devices that relieve pressure and redistribute the weight away from bony prominences. Several mattresses and seat cushions are commercially available which will accomplish this goal, however objective guidelines are needed to assist professionals in selecting the most effective surface for each individual.

This need was addressed at the Texas Rehabilitation Engineering Center and the PEP (pressure evaluation pad system) was utilized to measure the pressure under bony prominences of individuals lying on various pressure relieving mattress surfaces.

OBJECTIVE

The objective of this study is to compare the effectiveness of various bed support surfaces in providing pressure relief and redistributing loads away from areas of bony prominence and to determine if body build affects relative effectiveness.

METHODOLOGY

Thirty (30) subjects were selected at The Institute of Rehabilitation and Research and were evaluated using the PEP system. The subject population is represented in Table 1, classified according to sex and body build.

Table 1

	Thin	Average	Obese	Total
Male	4	8	1	13
Female	5	10	2	17
Total	9	18	3	30

Subjects were tested in the supine, prone and sidelying positions. The bony areas monitored in the study included the scapulae, sacrum, posterior and anterior iliac crests and right and left trochanters. The six (6) therapeutic mattress surfaces studied were the Stryker, ROHO, Foam Puff Pak 2", Foam Puff Pak 4", Gaymar Alternating Pressure Pad, and Lapidus Air Fluidized Bed. A standard hospital bed was used as a control surface.

Procedure for Pressure Evaluation

All subjects were tested on a standard hospital bed with each of the test mattresses. The test objectives and the equipment being used were explained to all of the subjects just prior to the test session. The PEP system was checked for safety and accuracy standards prior to each test session. The subjects were instructed to remove all objects from any pockets and remove their belts and shoes. The transducer pad was then placed between the mattress and the areas of the subject's body being monitored. Bony prominences were palpated and the corresponding lights were noted on the data collection form. The magnitude of the maximum pressure for each bony prominence was recorded. To improve the reproducibility and the accuracy of the maximum pressure measurements, the readings of maximum pressure were taken three (3) times and the average of the three readings was recorded for each bony prominence. Standardization in the sidelying position for all subjects was achieved by using a goniometer to position the hips in 45° of flexion. The trunk was positioned perpendicular to the support surface and parallel to the long axis of the mattress. Each subject was instructed not to move while the readings were being taken. For scapular and sacral pressure measurements the subjects were placed in a supine position.

RESULTS

Results of the study are based on the analysis of the maximum pressures measured under the bony prominences on all seven (7) mattresses. The mean value for the trochanter pressures on the various surfaces are illustrated in Figure 1. In the process of preliminary testing, it was noted that there were no clinically significant pressures recorded under the posterior and anterior iliac crests in the positions that were tested in the study. The results presented in this report, therefore, are based on our analysis of the maximum pressures under the right and left trochanters, scapulae and sacrum.

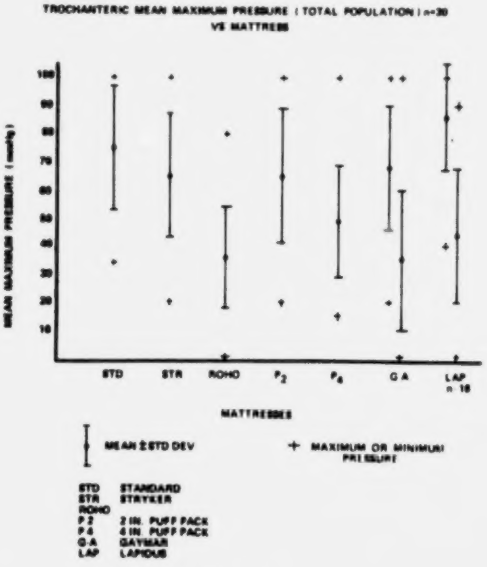


Figure 1

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*Norms for body types are taken from Scientific Tables, Documenta Geigy, 6th Edition, 1962, "Average Weights for Adults"

An analysis of the statistical significance of the difference between the standard mattress (control) and the six (6) therapeutic mattresses and Stryker vs. the six (6) remaining mattresses was conducted using the Student "T" Tests. Levels of significance for the observed differences between the mattresses are summarized in Table 2.

Table 2
Summary of "T" Tests

Bed Surface vs. Standard Mattress	Pressure Site	Level of Significance
Stryker	Tro.	0.01
	Sac.	no sig.
	Scap.	0.01
ROHO	Tro.	0.005
	Sac.	no sig.
	Scap.	0.01
Puff Pak 2"	Tro.	0.01
	Sac.	no sig.
	Scap.	0.025
Puff-Pak 4"	Tro.	0.005
	Sac.	no sig.
	Scap.	0.10
Gaymar(low cycle)	Tro.	0.005
	Sac.	no sig.
	Scap.	0.10
Lapidus(low cycle)	Tro.	0.005
	Sac.	0.10
	Scap.	no sig.

When compared to the standard mattress, there appears to be a significant pressure reduction (and redistribution of pressure away from the bony prominences) under the trochanters for all of the therapeutic mattresses, with a slightly greater difference for the ROHO (see Figure 1). However, when compared to the Stryker Mattress, for the trochanter, there is no significant difference with the Puff Pak 2". All the remaining mattresses were statistically more effective in reducing trochanteric pressure than the Stryker system.

Under the sacrum, there is no significant difference between any of the mattresses and the standard mattress, except for the "high" cycles of the Gaymar and Lapidus systems which appear to produce slightly higher pressures than the standard mattress and all the other mattresses (see Figure 2).

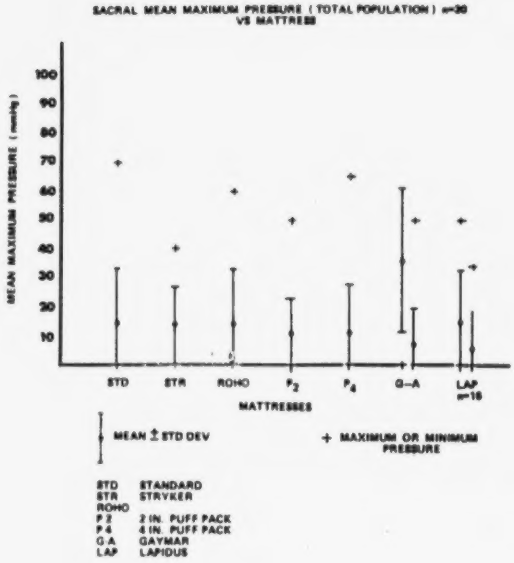

Figure 2

For the Scapulae, Stryker is slightly more effective than most other mattresses, with the exception of the Puff Pak 2" where there is no significant difference and the Gaymar (low cycle) which rendered slightly low pressure (see Figure 3).

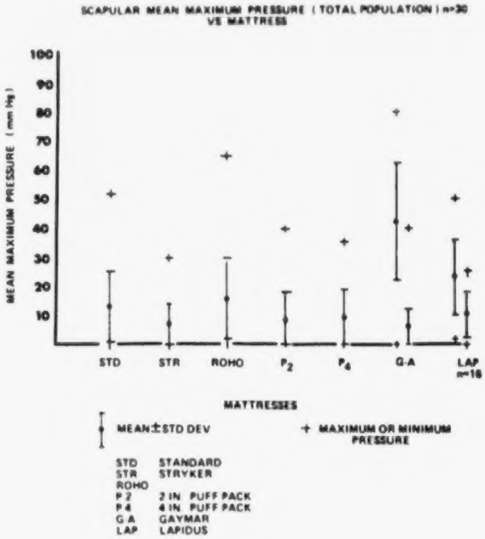

Figure 3

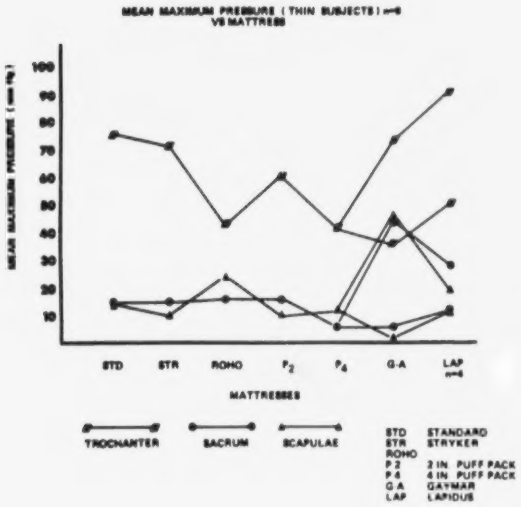

Figure 4

CONCLUSIONS

1. All of the therapeutic mattresses appear to be significantly more effective in producing lower pressures than the standard mattress, especially under the trochanters.

2. The ROHO mattress appears to be slightly more effective in reducing the maximum pressures under the trochanters than the other therapeutic mattresses tested. However, even though the ROHO appears to be more effective in rendering lower pressures, it may be impractical from the nursing care standpoint, due to the difficulty of using it.

3. When considering all of the pressure areas monitored in the study, the therapeutic mattresses are all of statistically equal value in reducing pressures. However, a particular mattress should be matched to a specific patient since, as can be seen from the ranges noted from each mattress, each subject did do better on one mattress than on the rest.

4. The Lapidus system has the disadvantage of a large pump, which can not be placed under the patient's bed due to its size. This may be a potential problem in some hospitals or home settings, as it is a safety hazard for those taking care of the patient.

5. Females generally have lower maximum pressure than males on all the mattresses tested.

6. There appears to be a slight difference between the "thin" and "average" body type subjects, with thin subjects having generally high pressures under the trochanters and the sacrum.

7. The magnitude of the pressure under the sacrum is often dependent on the subject's lower back curvature which causes the pressure to shift to the coccyx.

ACKNOWLEDGEMENT

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REFERENCE

1. Noble, P.C., "The Prevention of Pressure Sores in Persons with Spinal Cord Injuries," World Rehabilitation Fund, International Exchange of Information in Rehabilitation, Mono. No. 11, 1981

Irena Herszkowicz, MOTR
Dept. of Neurophysiology
The Institute for Rehabilitation and Research
1333 Moursund Ave.
Houston, Texas 77030

ASSISTIVE DEVICE FOR LOADING FLOPPY DISKS INTO APPLE II DISK DRIVE

Ronald L. Kett, M.S., Simon P. Levine, M.A., M.S.,
Lincoln A. Jaros, B.S., Micheal A. Fenwick, R.T.O.

University of Michigan Hospitals; Ann Arbor, Michigan

INTRODUCTION

Many disabled individuals have limited use of microcomputers because they cannot independently insert and remove floppy disks. To perform this task other machines have been built but they have their disadvantages. The VISTA V1200 (1) is available commercially but is quite expensive. A second system (2) is not available commercially. Both products work on the same principle and are motorized, necessitating a complicated motion that is expensive to build.

A simple mechanism has been constructed allowing selection, insertion and removal of 5.25 inch floppy disks for the Apple II microcomputer system. It is a purely mechanical system and can be operated with a mouthstick or limited hand function.

MATERIALS AND METHODS

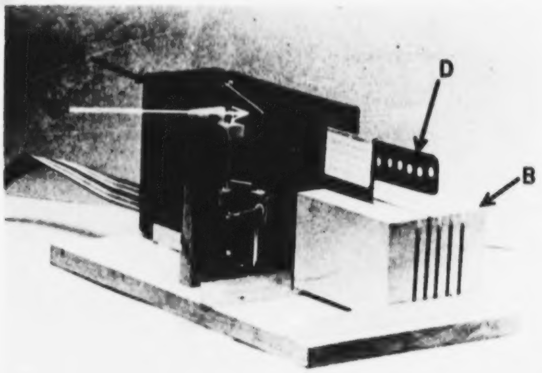
Design Criteria

The design criteria for this machine included:

1. It would be operable with the use of a mouthstick.
2. It would be a simple mechanical device to minimize cost and maintenance.
3. It would handle a minimum of five floppy disks.
4. It should be modular allowing a second disk drive to be added.
5. It would be designed for an Apple II microcomputer but adaptability to other systems would be considered.

Design

Operation of the machine can be divided into four areas: The disk drive, the rack to store the floppy disks, the mechanism to open and close the disk drive latch, and a disk attachment to assist insertion and removal of the floppy disks. A photograph of the first prototype system is shown below.



The disk drive is mounted on its side so that the disks to be loaded and unloaded are in the vertical plane (A-photo). When the user is facing it, the latch opens to the left. A second disk drive can be mounted adjacent to the first.

Disks are stored vertically in the rack (B-photo). The rack is mounted on guides so that it can slide to align the appropriate disk for loading into either disk drive. The rack has a series of slots in it which are 0.12 inch wide and 3.50 inches deep to hold the floppy disks.

A lever system operates the disk drive latch (C-photo). The same mechanism both opens and closes the latch. It is mounted behind the disk rack to the left of the disk drive.

Attached to the top corner of each disk is a thin strip of rigid material with several holes punched in it (aluminum was used for the prototype) (D-photo). This provides a means to insert and remove the disk from the drive and minimizes the head and neck movement required. A minor modification on the tip of a mouthstick is necessary to push and pull the floppy disk.

RESULTS

The machine has been tested with two Spinal Cord Injury patients. A patient with a recent C4-C5 injury required the mechanism to be directly in front of him due to limited head and neck strength. A patient with a C2-C3 injury performed well with the machine either in front or to his side. Both patients were able to operate all the functions of the machine without assistance.

DISCUSSION

The machine has the potential to provide a low cost maintenance free method for handling floppy disks. Even though it has been designed for use with a mouthstick, it should be useful to many individuals for manipulating floppy disks by hand.

References
1. Vista Computer Company, Inc. Santa Ana, CA

2. Raymond E. Fulford, "Mechanical Floppy Disk Loader for Computer Disk Drives." **Proceedings of the 5th Annual Conference on Rehabilitation Engineering**. August, 1982, pg 43

Ronald L. Kett, M.S.
Rehabilitation Engineering Division
Dept. of Physical Medicine and Rehabilitation
E3283 University of Michigan Hospitals
Ann Arbor, Michigan 48109

9.13P

BED TURNER

K.M. Hunter, P.Eng. V. Ko, B.A.Sc. R. Suggitt, B.A.Sc.
G.F. Strong Rehabilitation Centre
Vancouver, B.C. Canada

ABSTRACT

A mechanical bed that allows the occupant to turn themself was designed and built. The bed was made for disabled persons who cannot obtain the services of a night attendant and require periodic turning during sleep. The primary requirement of the turning is to prevent bed sores. The turning is done mechanically and can be initiated by the bed occupant or set to turn automatically. The overall appearance of the bed is more suitable to a group home setting rather than a hospital or institutional environment.

INTRODUCTION

A number of disabled people who require assistance in turning at night and are currently living in extended care units in British Columbia are eligible for transfer to group homes. Night time assistance for group homes is not provided by the government. Some patients, who live at home, rely on family members to get up at night and do the turning every two hours. The Bed Turner, an electromechanical device, was designed to automatically turn the patients who cannot turn themselves independently at night. For patients living in extended care units, this device would allow them to leave the institutional environment and live in a group home. For patients living at home, the Bed Turner would lessen the burden of getting up at night for other family members.

The intended users of the Bed Turner exhibit neuromuscular problems, such as muscular dystrophy, multiple sclerosis, cerebral palsy and spinal cord lesions. Bed sores may occur as a result of sleeping in the same position too long at night, however, bed sores can be prevented by having someone turn the patient approximately every two hours during the sleep period.

The development of the Bed Turner was funded by the Muscular Dystrophy Association of Canada. Two engineers, Vick Ko and Bob Suggitt, supervised by Kate Hunter, P. Eng., worked on the design and fabrication of a prototype which was built at the G.F. Strong Rehabilitation Centre and is presently undergoing field trials.

BACKGROUND

Many disabled people require assistance in turning during the night to relieve localized pressure points on the body since continued pressure on one area may cause bed sores. Turning a person from their back to their side is a somewhat complicated procedure to do mechanically. A night attendant can do the turning and leave the patient in a fairly stable side position by proper placement of the legs and arms.

To achieve the same goal with a machine, the patient must be rolled to their side, an unstable position. The body is free to fall either forward or backward and if the patient is asleep, he cannot be expected to assist in the turn. Stability in the side position is achieved by proper placement of the legs and arms. The upper leg may be bent, with the knee placed forward of the lower knee to keep the body in a stable side laying position. Alternately, both legs may be slightly bent and the upper leg resting on top of the lower leg to hold the body position.

The Bed Turner mattress articulates and results in almost a side laying position of the patient. The Bed Turner mattress is divided and hinged longitudinally. It is suspended by pivots and bearings that allow the center board to tilt. A person sleeping on the bed with the mattress in a tilted position, perhaps to the right, would feel most of the mattress pressure on the right side of the body. After some time period, the mattress changes its position to a flat back position or to the opposite side position. This results in a shift in the body pressure areas. A true side laying position is not achieved, but there is a redistribution of pressure. This eliminates prolonged localized pressure areas, and as a result, prevents bed sores.

The mattress and bed configuration is similar to a commercially available model, the LIC Turnover Bed.[1] The LIC Turnover Bed has more features than required by the Bed Turner and has the institutional appearance of a hospital bed, which makes it aesthetically undesirable for a group home setting. Also, the cost of the LIC bed was prohibitive.

The Bed Turner was designed with the following criteria:

- suitable for disabled individuals with neuromuscular disorders
- simulate the LIC bed articulation
- aesthetic appearance for a group home setting
- very simple operating mechanism
- inexpensive
- low maintenance.

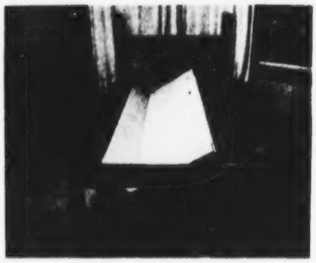


Fig. 1. Bed Turner without Mattress

Fig. 2. Control Unit

MATERIALS AND METHODS

Wood was selected for the frame of the Bed Turner for many reasons: woodworking shop space was available; wood is easier to work with than metals; the finished appearance of the product is high and the strength of the material is more than sufficient. The bed design used a conventional furniture design and does not have an institutional appearance.

The mattress base is divided longitudinally into three sections. The sections are stiffened by 2"x4" beams and joined by piano hinges. The middle section of the mattress base is pivoted at the bed head and foot boards. The wings of the mattress base are connected to the head and foot boards via roller-slot assemblies. This suspension system allows the mattress to assume the positions attainable by the LIC Turnover Bed.

Positioning of the mattress is done with a Duff Norton Minipac Actuator.[2] This device is an extensible arm, completely self contained and self locking. One end of the Minipac is firmly mounted to the bed frame and the other is mounted to the central mattress board. The extension of the actuator arm controls the angle at which the center board tilts.

The overall height of the bed was selected so that the surface of the foam mattress would permit easy transfer to and from a wheelchair. The prototype bed was built for people up to 180 pounds (82 kg) weight and up to 6 feet (1.83 m) tall. The group that initially uses the Bed Turner are light weight young adults.

A firm foam was used for the sleeping surface. The foam was divided into three long strips and covered with a plastic coated waterproof fabric. The three cushions are held together loosely with a bed sheet. The loose tension of the bed sheet permits the cushions to follow the bending movements of the wood mattress frame.

Control of the mattress position is done with electronic circuitry. The patient can select the mattress position by operating the controller in its manual mode. The tilt of the bed can be changed by pressing a button on the control unit. The user can also set the control to automatic. In this mode, a timer causes the bed to turn at pre-set intervals. The interval between turns can be adjusted from 1½ to 2½ hours.

The control unit does not allow the patient to select the range of tilt or the direction of tilt, however, the bed can be pre-set to limit the angle of tilt. Absolute control over the direction and angle of mattress tilt is available using a separate auxiliary control unit, which would not normally be used by the patient. The reason for not allowing the patient full control over the tilting action was to make the tilt control less prone to malfunction from human error.

Mercury gravity switches sense the position of the mattress and this switch information drives relays, which in turn control the actuator motor. The amount of actuator extension determines the position of the mattress. The actuator is started automatically by the electronic timer or manually by the patient. The mercury switches stop the actuator and set the correct direction for the travel of the actuator.

Four different modes of tilting action are available. The NORMAL mode is a back to side to back to the opposite side cycle of tilting. A SIDE to SIDE mode is available to tilt the patient from one side to the other without stopping in the flat back position. The patient can also limit the tilting to only one side of the body with the LEFT SIDE or the RIGHT SIDE mode.

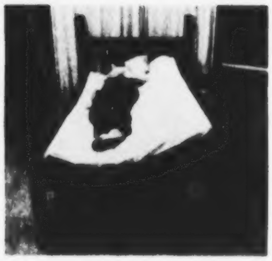


Fig. 3. Bed on Right Side

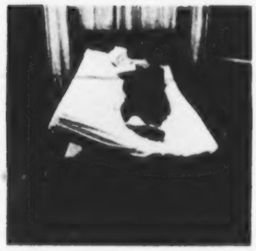


Fig. 4. Bed on Left Side

RESULTS

Initial testing of the Bed Turner revealed that the desired shift in body pressure areas was achieved. A firm foam mattress was first tried and it proved to be too hard for some patients. A softer foam was tested and it was found to be more suitable. The softer foam allowed the patient to lie in a true side lying position, a feature we had not fully expected.

Some patients required special pillowing to support their knees and restrict head movement during turning. The noise produced by the motor mechanism was noticed and further work is planned to alleviate this problem.

One feature inherent in the Bed Turner design is its potential for custom fitting to an individual's preference and physical features. The size of the bed can be tailored to the user's build; the foam firmness and pillowing is specified by the user and even special requests regarding the user interface and control characteristics can be accommodated.

The outcome of the clinical testing looks promising and commercial manufacture of the Bed Turner is contemplated.

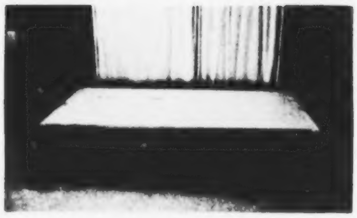


Fig. 5. Bed Turner in Flat Position

ACKNOWLEDGEMENTS

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The Muscular Dystrophy Association of Canada, for funding the project;

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REFERENCES

1. The LIC Turnover Bed. Contact:
LIC Care
Svetsarvegen 20
S-17183 SOLNA
Sweden

2. Duff Norton Actuator Company. Contact:
Duff Norton Company
P.O. Box 32605
Charlotte, North Carolina 28232
U.S.A.

Rehabilitation Engineering Department
G.F. Strong Rehabilitation Centre
4255 Laurel Street
Vancouver, B.C. Canada
V5Z 2G9

A MOVABLE CHIN-PAD STEERING CONTROL DEVICE FOR AN ELECTRIC WHEELCHAIR

Robert J. Coleman, PhD; William F. Brady; David L. Crot

The University of North Carolina at Charlotte

ABSTRACT

Mr. G. is a quadriplegic who uses an electric wheelchair for personal mobility. He operates this wheelchair with a chin-pad "joystick" steering control device. This device is an obstacle to Mr. G. when he uses his mouthstick. He needed someone to move the control device out of his way. It also had to be returned to its position when he completed his work.

A simple, inexpensive solution to the problem is described using an electric motor and a system of gears to swing the control pad to the side of the chair in a compound arc. The electric motor uses the battery pack of the chair as the power source. Mr. G. is able to operate this mechanism by pressing switches with his chin.

INTRODUCTION

The purpose of this project was to adapt an electric wheelchair for a quadriplegic so that he could work with a mouthstick without the obstacle posed by his chin-pad steering control device. Mr. G. is a very active person for a quadriplegic. With a mouthstick he is able to turn pages of a book, answer a specially designed telephone, and paint with a mouthstick paintbrush. However, he needs someone to move the steering control device before he is able to use his mouthstick and to move it back when he is through.

Considering the problem, there are many alternative solutions, some of which were completely different steering devices, others concerned with moving his present steering control device. New types of steering devices considered were acoustic, optical, and pneumatic. Optical and acoustic devices were rejected due to their high costs and Mr. G. may have had trouble operating the optical control since he only has slight control in balancing his body. The pneumatic control device was considered too dangerous for him to operate due to his poor lung capacity.

Next, considerations were made based on moving the present chin-pad steering control. This could be accomplished by several different means. In moving the chin-pad, one must be cautious not to surpass the limits of Mr. G.'s particular situation. The chin-pad must not be raised too high to fit into his wife's van. Nor could it swing too far to the side, thus preventing the chair from fitting between his bed and the wall.

A system was designed which would lower his control pad by pivoting it in a compound arc in front of his chest. This method would allow him to use his mouthstick without interfering with any of his activities. Of course, the chin-pad would still be able to swing up as it was designed to do. In this way he would still be able to be helped into and out of his chair when necessary. Hydraulic control was investigated but a decision was finally made to move the control pad with a simple mechanical system employing an electric motor and a series of gears.

LITERATURE REVIEW

The main obstacles confronting quadriplegic's efforts to live more normal lives are usually the problems of communication and mobility (11). Any task which a severly handicapped person can learn to do for himself is a major accomplishment in that it affords some degree of independence from the schedules of those whose job is to care for the person (5).

In the literature there are many references to devices which aid the handicapped in communication, mobility, or environmental control. Most these methods could be adapted to perform other tasks.

Most of the existing control devices for quadriplegics can be classified into four groups. These are acoustic, optical, pneumatic, and "joystick" type controls. The majority of motor driven wheelchairs depend on a joystick control. The control pad is mounted on one of the arms of the chair when the patient has control of an arm, or on a chin-pad if arm control is not possible but control of the neck muscles is sufficient. Aylor, et al (1), altered the circuitry of the signal processor of a joystick controller to enable patients without good gross motor control to be able to operate a motorized chair to drive in a straight line or maneuver tight corners.

Another type of control is by use of pneumatic switches that a patient can operate by sipping or puffing on a tube (12). Vasa and Lywood (15) built a puff and sip typewriter control which was later adapted to operate on the keys of a computer terminal.

Optical controls consist of a light emitting diode attached to glasses or a headband and a photosensitive unit attached to the device to be controlled. These have been used mainly as a means of operating typewriters. Seode, et al (14), built a lightspot operated typewriter for quadriplegics which enabled some to type at one hundred characters per minute. Durie and Cote (3) built the same sort of device for a child with cerebral palsy. The photosensitive cells were much larger so the patient could easily direct the light beam to the targets. Another type of optical control device, built by Simmons and Radcliffe, (13) was for the control of an orthotic hand. With this device the hand followed the path of the light beam and a patient could move small objects with the orthoses.

Audio controls depend on either sounds, such as tongue clicks, or on actual words. While a system that uses mere noises is probably simpler to use and less expensive, a word-controlled system offers more versatility through the implementation of a higher number of commands.

Ramey, et al, (10) built a hum-controlled electric wheelchair which responds to four musical tones. These tones range from 130 to 555 Hz and command the chair right, left, forward, and stop/reverse. The system is a plug-in replacement for an existing joystick control. When the forward command is hummed, the chair will continue until ordered otherwise. Other commands must be hummed for the duration that they are required.

Clark and Roemer (2) used a voice recognition system with an eight word vocabulary to control an electric wheelchair. Voice recognition rates of up to ninety percent were obtained in tests. The limit of background noise was at seventy-seven decibels. Above this level the system became difficult to operate. Operation was impossible at the eighty-five decibel level.

A thirty-two word vocabulary was used in a wheelchair and environmental control unit designed by Rusk, et al (11). The individual commands consisted of a two word sequence to prevent unexpected accidental commands. The larger vocabulary enabled the system to control fourteen environmental controls in addition to the chair itself.

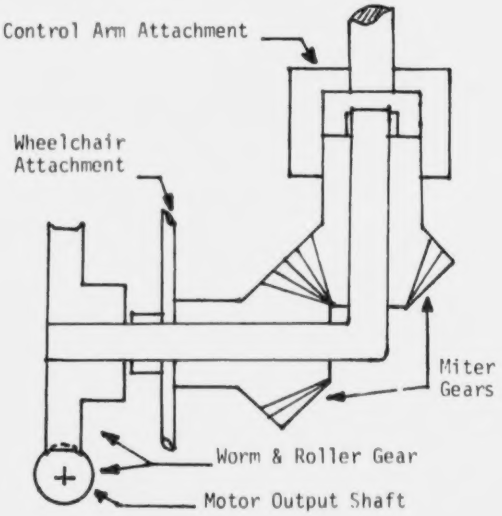

Figure 1. GEAR AND SHAFT CONFIGURATION

MATERIALS AND METHODS

The electric motor and gear system is shown in Figure 1. The shaft from the electric motor turns the worm gear, which causes the roller gear to turn. This gear is attached to a shaft which passes through the miter gear, which is attached to the chair. The shaft then makes a right angle toward the front of the chair and passes through the second miter gear. The shaft on which the control pad is attached is fixed to this second miter gear. In this way the turning of the motor shaft is transformed into motion in two planes.

This motion can best be visualized by imagining a right-handed coordinate system attached to the miter gear which is allowed to move. The x-direction is pointing to the left of the chair. The y-direction points straight forward with respect to the chair. The z-direction is downward.

As the miter gear is forced downward by the shaft, a rotation occurs about the x-axis. At the same time, the gear itself is turning due to contact with the other miter gear (fixed to the chair). This causes a rotation about the new y-axis. Since the miter gears have a one to one ratio, a ninety degree rotation of one plane causes a ninety degree rotation of the other.

As described above, the materials involved include two matched miter gears, a worm and roller gear set, the shaft, mounting materials, and an electric motor. The miter gears are standard straight-tooth gears. The worm and roller gear arrangement chosen depended on the rotational speed of the motor. The final speed needed was between two and four revolutions per minute. Also, the motor had to produce adequate torque to operate the mechanism.

Based on the arrangement shown in Figure 2, the maximum torque required would be about 27.4 inch-pounds. This assumes the situation where the arm is being raised from the operating position. The arm shape and measurements may be modified to a particular situation.

A surplus windsheild wiper motor from a school bus was obtained which produced twenty inch-pounds at forty revolutions per minute. A worm and roller gear arrangement that reduced the rotational speed to one-tenth would increase the torque ten times. This motor and this gear arrangement produces more than enough torque and a rotational speed of four revolutions per minute.

RESULTS

The mechanism was constructed as planned and has been tested on a wheelchair similar to Mr. G.'s. The method by which Mr. G. will activate the device has not yet been finalized. Two double pole, single throw switches are required so that the polarity may be reversed in one of the switches. This will allow the motor to be reversed and the arm moved freely in either direction. The switches may be placed on either side and operated by head movement from side to side or a rocker switch may be operated by chin movement. The switches used and their location will be based on Mr. G.'s preferences.

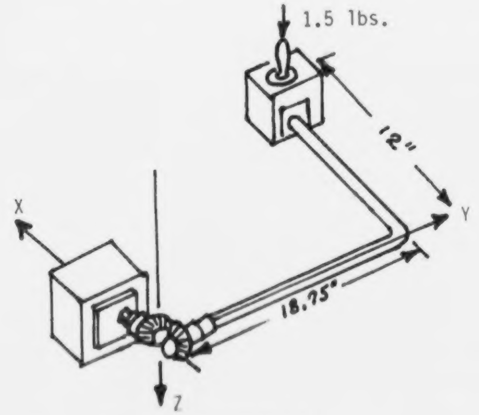

Figure 2. TORQUE REQUIREMENTS

$$\vec{M} = \vec{R} \times \vec{F} = (12\hat{i} + 13.75\hat{j}) \times (1.5\hat{k})$$
$$= 20.6\hat{i} - 18\hat{j}; \quad |M| = 27.4 \text{ in.-lbs.}$$

DISCUSSION

As was discussed earlier, we could have attempted to develop an alternative means of operating the chair. This would not only have taken us a long time to complete, but, if it worked, would have required Mr. G. some time to learn to operate.

The relatively low cost of this system also makes it quite attractive when compared to any other system.

SUMMARY AND CONCLUSIONS

The method we chose for Mr. G.'s chair, although not the most elaborate, seems to work very well. Other, more complicated methods of moving the chair (optical, acoustic, pneumatic) are obviously worthy of some further study and research. These methods were rejected because we felt these methods could not be fully researched and implemented under the time and budget limitations we faced.

REFERENCES

1. Aylor et al. 1979. Versatile wheelchair control system. Medical & Biological Engineering & Computing 17, no. 1:110.
2. Clark and Roemer. 1977. Voice controlled wheelchair. Archives of Physical Medicine and Rehabilitation 58, no. 4:169.
3. Durie and Cote. 1978. The headlight: a light-operated remote control device for the handicapped. Journal of Medical Engineering and Technology 2, no. 3:139.
4. Flaghouse, Inc. Wholesale Catalogue. fall 1979.
5. Howarth, Winifred. 1970. Living at home as a totally disabled person. International Nursing Review 17:238-253.
6. Lehman et al. 1974. Wheelchair propulsion in the quadriplegic patient. Archives of Physical Medicine and Rehabilitation 55, no. 4:183-186.
7. McGee and Hertling. 1977. Equipment and transfer techniques used by C6 quadriplegia patients. Physical Therapy 57, no. 12:1372-1375.
8. Prentke, Edwin M. 1970. A chin switch for control of orthoses. Archives of Physical Medicine and Rehabilitation 51, no. 7:436.
9. Prentke Romich Company. Electronic Aids for the Severely Handicapped. December 1978.
10. Ramey et al. 1979. Hum-controlled electric wheelchair. Medical & Biological Engineering & Computing 17, no. 6:776.
11. Rusk et al. 1978. Voice-controlled devices for the severely disabled. Journal of the American Medical Association 239, no. 22:2367.
12. Sell et al. 1979. Environmental and typewriter control systems for high-level quadriplegic patients: evaluation and prescription. Archives of Physical Medicine and Rehabilitation 60, no. 6:246-252.
13. Simmons and Radcliffe. 1976. A new method for optical control of manipulative-type orthoses for high-level quadriplegics. Medical & Biological Engineering 14, no. 3:282.
14. Soede et al. 1973. A lightspot operated typewriter for severely physically handicapped patients. Ergonomics 16, no. 6:829-844.
15. Vasa and Lywood. 1976. High-speed communication aid for quadriplegic patients. Medical & Biological Engineering 14, no. 4:445.

Robert J. Coleman, PhD
Associate Professor
Engineering Science, Mechanics and Materials
UNCC Station
Charlotte, NC 28223

10.1

DEVELOPMENT AND TESTING OF A HANDHELD LOAD CELL FOR IMPAIRMENT EVALUATION

Timothy K. Hight
Department of Mechanical Engineering
Duke University

INTRODUCTION

The modern Physical Therapist has only a limited number of tools available to him for objectively measuring the state of health, or progress of recovery, of a patient. This is particularly evident in the evaluation of patient muscle strength and, by corallary, neuro-muscular health. Some relatively sophisticated and expensive equipment, such as the Cybex system, is available for muscle strength evaluation, but it is usually not practical or cost effective for everyday examination. Standard practice currently dictates procedures whereby the therapist resists the muscular action of the patient with his own muscular forces and subjectively evaluates the strength of that muscle group relative to the therapist's memory of the equivalent "normal" population and of that patient's previous tests. This type of evaluation is prone to error and uncertainty and is not readily comparable between different therapists.

It has been the goal of this project to develop a convenient, low cost, and reliable device which would provide objective measures of the muscular strength of a patient. This type of device would have three major benefits to the therapist. First, data could be realistically collected on patient and healthy populations which would allow norms to be established. Second, a reliable relative measure of patient progress would be provided, enabling evaluations of treatment procedures. And third, students could be more readily taught to interpret force levels exerted by a patient. Thus this device can be utilized as a research, clinical and teaching tool.

The work toward these goals has progressed in two stages. The first step involved the initial problem definition and the design and construction of the first prototype. A series of 50 normal subjects were evaluated with this device. The second stage of the project involved the design and building of the second prototype. A very limited series of tests have been run using this device.

BIOMECHANICS

Before proceeding with a description of these devices, it is appropriate to briefly discuss the relevant biomechanical concepts. Figure 1 shows a schematic representation of a typical manual muscle test on a limb using the load cell. The first criteria which must be met is that the system is static. That is, as long as the therapist can maintain a relatively stationary position of the patient's limb, then acceleration forces are not significant. An analysis will show that acceleration terms will be insignificant for any but the most violent motions.

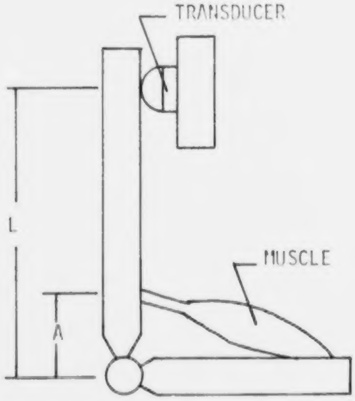

Figure 1. Schematic of muscle test on biceps

The second criteria has to do with the positioning of the load cell. Since the muscle force, acting at a distance A, and the therapist's resistance, acting at a distance L, are balancing a moment about the particular joint, the force measured at the load cell will be a linear function of the distance from the joint (L), given a constant muscle force. Thus, assuming a steady system, good repeatability of load cell placement is essential, but also sufficient, for accurate and repeatable muscle force measurement.

It is also important to note that any springs placed between the load cell and the limb, e.g. padding, do not effect the equilibrium forces, and hence do not effect the load cell reading or the muscle force. For this reason the load cell plate can be padded for comfort of the patient and the therapist.

PROTOTYPE DESIGN AND TESTING

The initial design concept was to develop a small force transducer which could be held in the therapist's hand and still allow him to perform the majority of standard manual muscle testing procedures. To meet these criteria, the transducer was designed using the configuration shown in Figure 2--two parallel steel plates separated by spacers with a strain gauge mounted to the underside of the top, more flexible, plate. The device was held in the palm of the therapist's hand and the strain gauged plate was opposed to the patient's limb. As the patient exerted force, the plate was deformed causing a change in resistance of the strain gauge. Through a Wheatstone bridge circuit this resistance change was measured as a voltage change which was output on a digital voltmeter. Additional circuitry was added to "hold" the maximum reading with a slow time decay for easier reading. A zero button reset the device to zero.

Tables 1 and 2 show the results of an initial testing program. Fifty normal college age volunteers (32 males, 18 females) were evaluated using two trials each of 10 standard muscle tests. These tests were carried out by an engineering student who had been given brief instruction in these procedures. The two columns of averages are for first and second trials of the same test. Results showed that 80% of the second trials were lower than the first, possibly indicating a slight loss in muscle strength during the test, or discomfort with the load cell. In general, results from one trial are within 15% of the results from the other trial. It is not clear how much of the variation is due to muscle fatigue and how much may be due to changes in operator technique or load cell position. More controlled tests will be needed to determine the relative contributions of these effects.

The initial testing sequence exposed a number of shortcomings of the first prototype. The two major areas concerned comfort and reliability. The relatively small, narrow and stiff plate of the load cell was very uncomfortable when pressed against a narrow bone, such as in the area of the wrist. Even with some padding the device did not encourage a maximum exertion in some tests and this probably was a contributing factor in the lower second test readings.

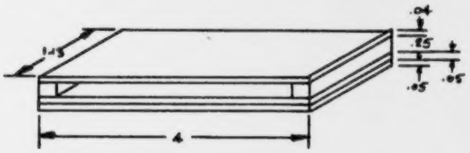

Figure 2. First prototype (dimensions in inches)

TABLE 1-AVERAGE FORCE RESULTS FOR 32 MALE SUBJECTS (POUNDS)

	MUSCLE GROUP	FIRST	SECOND
SITTING			
	Biceps	36	30
	Brachioradialis	28	23
	Quadriceps	45	40
	Anterior Deltoid	16	14
	Middle Deltoid	12	10
	Hip Flexors	23	21
	Hip External Rotators	11	9
SUPINE			
	Neck Flexors	5	4
	Triceps	15	13
PRONE			
	Hamstrings	23	21

TABLE 2-AVERAGE FORCE RESULTS FOR 18 FEMALE SUBJECTS (POUNDS)

	MUSCLE GROUP	FIRST	SECOND
SITTING			
	Biceps	22	20
	Brachioradialis	19	15
	Quadriceps	36	31
	Anterior Deltoid	11	8
	Middle Deltoid	8	7
	Hip Flexors	17	17
	Hip external Flexors	5	4
SUPINE			
	Neck Flexors	1.5	1
	Triceps	12	10
PRONE			
	Hamstrings	17	16

The second problem was related to the very small deflections in the sensing plate. To maintain a linear response, the deflections were kept small, but this meant that the signal voltage had to be greatly amplified. The large amplification made the electrical system very difficult to zero and also very sensitive to fluctuations in the power supplies (batteries).

These difficulties led to the development of the second prototype design. The main objectives of the redesign were to make the transducer more comfortable and to simplify and stabilize the electronics.

The force transducer was made more comfortable by increasing the size of the top plate and replacing the flat metal with a padded dome of plexiglass (see Figure 3). The slight curvature of the dome allows for a more uniform distribution over a larger area of the force on the patient.

In order to stabilize and simplify the electronics, the strain gauge approach was abandoned in favor of a piezo-electronic force transducer. This device produces a direct voltage in response to load. This eliminated the need for the very high amplification of the previous system.

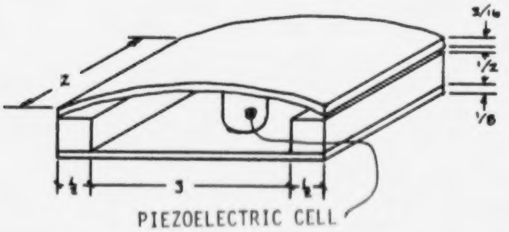

Figure 3. Latest prototype (dimensions in inches)

Initial testing of the second generation device has been promising. Results shown in Table 3 for three trials of tests performed on a single subject show a much higher consistency than previously attained. Other difficulties have, however arisen.

The current system, in an effort to stabilize the power source, is driven by a relatively large lantern battery. This makes the system rather cumbersome. Smaller rechargeable batteries or an AC power source will be substituted to overcome this problem. In addition, the electronics have been oversimplified in this version and will be updated. A 'sample and hold' microchip will be added to the system as well as zeroing and clearing circuits.

SUMMARY AND CONCLUSIONS

A second generation force transducer for use by physical therapists during manual muscle testing has been developed, and initial testing and refinement are underway. This device has the potential for becoming a valuable tool for researchers, clinicians and teachers. A biomechanical analysis of the system shows that accurate and repeatable muscle force measurements can be insured by careful transducer placement and evaluation techniques, and this is also indicated in the preliminary test results.

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ADDRESS

Tim Hight
Department of Mechanical Engineering
Duke University
Durham, NC 27706

TABLE 3-PRELIMINARY FORCE RESULTS FOR MALE SUBJECT USING NEW TRANSDUCER (POUNDS)

	MUSCLE GROUP	FIRST	SECOND	THIRD
SITTING				
	Biceps	40	38	40
	Brachioradialis	38	36	36
	Quadriceps	44	46	45
	Anterior Deltoid	15	12	13
	Middle Deltoid	22	22	22
	Hip Flexors	28	27	27
	Hip External Rotators	18	18	18
SUPINE				
	Triceps	18	20	18
PRONE				
	Hamstrings	24	22	22

OBJECTIVE CORRELATES OF CLINICAL JUDGEMENT OF TREMOR SEVERITY

Veronique P.A.M. Pardoel*, Bernard D. Adelstein**, Jorge A. Romero***, Michael J. Rosen**
*State University of Leiden, The Netherlands, **Massachusetts Institute of Technology, ***Brockton V.A. Medical Center, Brockton, Massachusetts

ABSTRACT

The goal of this study was to determine which mechanical tremor parameters would be best correlated with subjective clinical judgement in determination of an objective rating of tremor severity. These variables were then incorporated into a hardwired device that presents and processes a goniometric pursuit tracking task and displays a numerical score.

Five subjects with varying amounts of tremor due to diverse etiologies were videotaped during a standardized clinical neurological examination. A group of neurologists individually viewed the videotaped examinations and were asked to rate the severity of the subjects' tremors. These rankings were compared with measures of the peak amplitude, RMS amplitude, "on time", frequency and burst control of goniometrically sensed wrist tremor obtained at the time of the clinical examination.

INTRODUCTION

Tremor is a mechanical oscillation superimposed on the limbs during purposeful activity or rest. It appears in both healthy and neurologically disordered people. In pathological cases, the tremor may be severe enough to obscure any underlying voluntary activity, making normal function difficult.

Neurologists classify tremor type and judge severity according to observations during a battery of movement and strength tests. Rating scales, such as AIMS (Abnormal Involuntary Movement Scale) and the Rockland Scale, typically subdivided into five or six levels, are often employed in diagnosis and evaluation of response to therapy. These assessments are clearly subjective, varying with the clinician's personal standards of scaling, and therefore are not uniform. Further, the coarse resolution in such a rating system may not show small but significant changes in tremor. An objective scoring instrument based on clinically relevant mechanical tremor characteristics would be useful. Determination of these parameters and design of a device incorporating them was the goal of the work described here.

MATERIALS AND METHODS

Subject Examination

Subject specifications for these experiments were tremor at the wrist and sufficient perceptual and cognitive ability to participate in the clinical examination and to perform a tracking task. The goals and protocol of the experiments were explaned to each subject in the process of obtaining their informed consent.

The assessment consisted of three parts: A) a standardized clinical examination; B) a wrist angle pursuit tracking test; and C) a wrist postural maintenance task. This entire protocol for each subject was videotaped (altering the field of view to suit the test) and edited with voice comments added. These included the patient's age, the number of years duration of his tremor and a brief description of the tests.

A. The "standard" clinical examination included thirteen tests normally administered by neurologists. The patient, while seated, was instructed to:

1. extend his arms and maintain this posture with his eyes open, then repeat the test with his eyes closed;

2. maintain his arms in an extended position while the physician tapped each hand sharply downward;

3. keep his arms extended while the physician pressed down on each arm and then suddenly released them;

4. alternately, using his index finger, touch his nose then the physician's finger;

5. oppose his thumb to each finger in sequence, with one hand, then the other;

6. tap with his index finger on the interphalangial joint of his thumb, first with one hand, then the other;

7. unbutton and button his shirt;

8. pick up and move small objects on a table top;

9. pick up a cup and bring it to his mouth as if to drink;

10. using a pencil, draw a circle within an annular track, then sign his name;

11. tap the pencil point within a 1 cm. diameter target;

12. tap rapidly with each hand on the table top; and

13. stand up and walk around the room.

B. The pursuit tracking display was presented on a CRT. The subject was seated facing the display with his forearm secured in a pronated position to the arm of his chair and his hand grasping the goniometer handle. Wrist flexion-extension angle, in a vertical plane, was sensed by a rotary potentiometer. The potentiometer signal was displayed as a vertically moving trace on the CRT along with a sinusoidally driven 0.125 Hz target.

The subject was instructed to keep these two traces aligned by raising or lowering the handle. Maximum target excursions corresponded to wrist angles of ± 40 degrees. The tracking task lasted for three minutes. The target and response signals were recorded on FM tape for off-line analysis.

C. During the postural maintenance task, the subject remained seated with the goniometer now removed. The subject was instructed to maintain the vertical position of his outstretched hand for 30 seconds with his forearm supported by the chair.

Neurologists Evaluations

The neurologists viewed the videotapes of the subjects' three tests and were asked to rank the severity of the tremors on a scale of zero through six, where zero was defined explicitly as the absence of tremor. As part of their answers, the neurologists explained the basis of their personal tremor severity rating.

To prevent any discussion among the neurologists before reaching their diagnoses and tremor scores, each viewed the videotapes separately.

RESULTS

Five tremor subjects participated in the experiments:

- -DS, a 70 year old male with Parkinson's disease of eight years duration;
- -MF, a 60 year old male with a familial tremor of 15 years duration;
- -WB, a 60 year old male with essential tremor of 37 years duration;
- -LM, a 66 year old male with essential tremor of 12 years duration; and
- -FP, a healthy 36 year old male who served as a control subject.

A sample of the tracking data recorded from subject DS is presented in Figure 1. Tremor frequency was derived from the band-pass filtered error signal in trace C. The rectified signal in trace D was used to detect peak amplitudes and to locate tremor bursts. Tremor "on time" was defined as the total time during which bursts over a given amplitude threshold were detected. RMS tremor (equivalent to the mean rectified error) was computed from the band-pass filtered error by signal averaging software.

Values for these five tremor parameters for the subject group are listed in Table 1.

Ten neurologists were interviewed. The hypothetical basis for their judgements of wrist tremor severity was divided into five categories: 1) comparison with other patients; 2) functional impairment; 3) absolute tremor amplitude; 4) tremor "on time"; 5) tremor frequency. The number of physicians of the ten who stated that they were relying on each of these categories is given in Table 2.

Table 2.

Categories	1	2	3	4	5
Number of Physicians	3	7	6	2	2

The tremor severity ratings given by the neurologists are presented in Table 3.

Table 3. Tremor Severity Scores

Subject	Physician #										Mean
	1	2	3	4	5	6	7	8	9	10	
DS	3	4	4	4	2	1	3.5	3	4	4	3.3
MF	1	1	1	2	2	1	2	1	2	3	1.6
WB right hand	3	5	5	2	4.5	2	5	4	5	3.5	3.9
left hand	3	5	5	3	4.5	2	5	4	5	3.5	4.0
LM	2	2	1	1.5	1.5	1	1.5	1	3	1.5	1.5

In addition linear regressions of the subjective severity ratings (dependent variable) of Table 3 on the objective measures (independent variable) of Table 1 were performed. All five objective measures were shown to have some form of relationship with the subjective severity scores at the 95 percent confidence level. The linear regression slope (β) range at the 95 percent level and the probability value for the null hypotheses ($H_o:\beta = 0$) are given in Table 4.

Table 4.

Objective Tremor Measure	Slope β	Prob. ($H_o:\beta = 0$)
Frequency	$0.19 < \beta \leq 1.14$	$0.0025 \leq P \leq 0.005$
RMS Tremor	$0.89 < \beta \leq 2.3$	$P \leq 0.0005$
Peak Tremor Amplitude	$0.213 < \beta \leq 0.407$	$P \leq 0.0005$
Burst Count	$0.0043 < \beta \leq 0.0837$	$0.01 < P \leq 0.025$
"On Time"	$0.0365 < \beta \leq 0.1035$	$P \leq 0.0005$

Table 1.

Subject	Hand	Pathological Tremor Frequency (Hz)	RMS Tremor (Degrees)	Peak Tremor Amplitude (Degrees)	Burst Count In 130 Seconds Of Tracking (# of Bursts)	"On Time" As % Of Total Tracking Time
DS	R	5.3	1.9	4.1	24	41
MF	R	6.0	0.4	1.0	38	33
WB	R	6.0	1.2	4.9	48	38
	L	7.5	1.6	9.4	52	57
LM	R	5.5	0.8	1.2	38	19
FP	R	*	0.3	0.4	*	*

*Control subject had only normal physiological tremor. All other subjects had pathological tremor simultaneously with higher frequency physiological tremor (1).

DISCUSSION

While functional impairment is very important to neurologists in assessing tremor severity, mechanical measures such as amplitude are also relevant. Bearing in mind the limited number of subjects and neurologists included in the study, there are regressive relations between the subjective severity rating and each of the variables derived from the goniometric wrist tracking record. Table 4 indicates that the most likely correspondence occurs for the peak and RMS tremor amplitudes and "on time" above a given threshold.

A portable Tremor Scoring Device which measures RMS tremor amplitude was developed as a result. It includes a bar graph display for prescription of the pursuit tracking task. The goniometric response is represented by one column of LED's along side a second one driven by a pseudo random target generator. The difference between the target and subject response is high-pass filtered to remove slower frequencies related to purposeful tracking. This signal is full-wave rectified and integrated over a 100 second time period. The integrated rectified high-pass filtered error (∿ cumulative RMS tremor) scaled in a range from 0 to 9999 is then displayed digitally to the clinician at the end of the trial. Important features of the Tremor Scoring Device are diagrammed in Figure 2.

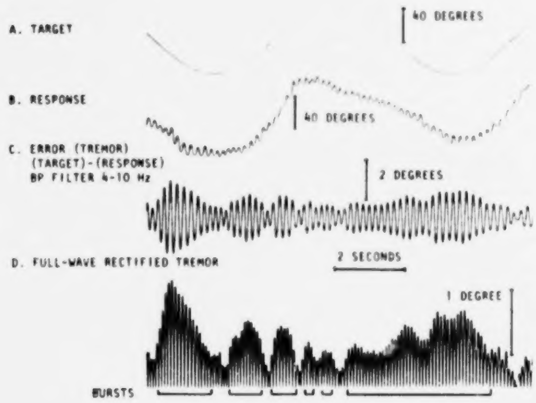

Figure 1. Sample Tracking Data
From Subject DS

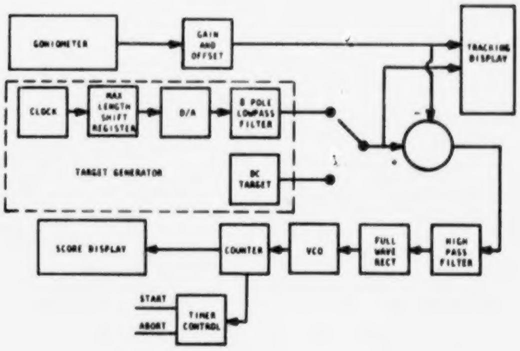

Figure 2. Tremor Scoring Device

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REFERENCES

1. B.D. Adelstein and M.J. Rosen, "The Effect of Mechanical Impedance on Abnormal Intention Tremor". Proceedings, 9th Ann. Northeast Bioengin. Conf., March, 1981.

Massachusetts Institute of Technology, Cambridge,
MA 02139

10.3

EVALUATION OF MUSCLE CONTRACTILITY AND HISTOCHEMISTRY AFTER UPPER MOTOR NEURON LESION

Richard L. Lieber
Division of Orthopedics and Rehabilitation
University of California, San Diego

ABSTRACT

A technique has been developed to determine the contractile characteristics of a single muscle fiber segment obtained from hemiparetic and hemiplegic patients. The single fiber is obtained from needle biopsies taken during visits to the rehabilitation clinic or from traditional biopsies taken during surgery. One end of the fiber is attached to an ultrasensitive force transducer and the other end to a high-speed motor. A low power He-Ne laser is shined perpendicular to the long axis of the fiber and a diffraction pattern is produced by the muscle. This diffraction pattern is converted to an analog signal, digitized and fed into an LSI-11™ minicomputer system. The minicomputer controls the experimental timing sequence during an experiment and thus affords the opportunity for precise experimental control.

After physiological experiments, the single fiber is then processed using histological analysis. Information obtained from these studies include: fiber type, oxidative capacity, maximum contraction force, calcium sensitivity, and maximum contraction velocity. Since changes in nerve-muscle interaction can change these parameters, these data can be used to monitor the time course of recovery of neuromuscular integrity during rehabilitation. Since only small amounts of material are used, long-term effects of various rehabilitative techniques can be determined in humans.

INTRODUCTION

Over 800,000 strokes and other upper motor neuron lesions occur each year in the United States. Although the location and severity of central lesions can be determined with a good degree of certainty, the ability to objectively evaluate motor function is limited. In this report, a method for evaluating muscle function is presented. This technique is minimally invasive to the patient (using needle biopsies) and noninvasive to the muscle fiber (using the laser diffraction technique). Because the interaction between nerve and muscle is intimate and predictable, we propose to monitor muscle function over time as an indicator of neuromuscular integrity. Using these techniques, muscle denervation, reinnervation, and change due to disuse atrophy can be measured.

METHODS

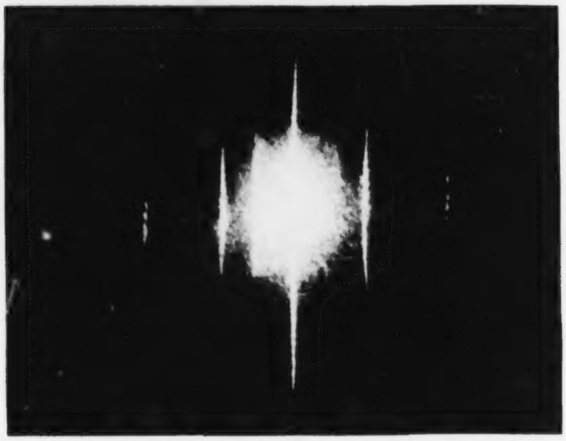
Fiber Preparation

1% Lidocaine is injected into the area of the tibialis anterior about 5 cm below the patella. A small (5 mm) incision is made in the skin and overlying fascia and a needle biopsy is taken according to the methods of Bergstrom (1). The biopsy is immediately transferred to a mammalian "relaxing" solution which is composed of (mM) : K EGTA (5), K Propionate (170), Mg Propionate (5), K_2Na_2ATP (5), and imidazole propionate (10) adjusted to pH = 7.0. Bathing in this solution prevents irreversible contraction of the muscle fibers due to depolarization. After bathing in relaxing solution for 15 minutes the fiber is transferred to a "skinning" solution composed of K EGTA (5), K Propionate (170), Mg Propionate (2.5), K_2Na_2ATP (2.5), and imidazole propionate (10) adjusted to pH = 7.0 (11). This solution renders the sarcolemma permeable to calcium ions, ATP, and other large molecules. After 30 minutes in skinning solution the fiber is returned to relaxing solution. The fiber can then be activated using micromolar concentractions of calcium (pCa greater than 6.0) or millimolar concentrations of caffeine, which induces calcium release from the sarcoplasmic reticulum (12).

After mounting, a low power Helium-Neon laser is shined perpendicular to the long axis of the fiber. The fiber behaves like a phase grating to incident laser light due to the periodic arrangement of the A and I bands and a diffraction pattern results (figure 1). The spacing between the lines (orders) of the diffraction pattern can be used to determine the average sarcomere length within the illuminated volume using the grating equation:

$$n\lambda = d \sin\theta$$

where n = the order number, λ = the wavelength of the laser in air, d = the grating spacing (sarcomere length), and θ = the diffraction angle measured (7). The diffraction intensity profile is converted to an analog signal using a linear photodiode array consisting of 128 elements. This analog signal is digitized by a video speed analog-to-digital converter and transmitted via ribbon cable to a custom interface within the LSI-11™. This data acqusition system has been thoroughly described by Lieber et al. (8). Subsequent experiments are performed using single-letter commands initiated from a console terminal. The data are acquired and stored on floppy disk for later analysis via an interactive FORTRAN program (9).



Mechanical Experiments

One side of the fiber is attached to an ultra-sensitive tension transducer (sensitivity = 30 mV/mg, resonant frequency = 3.7 kHz), and the other side to a high speed motor (step change in length from 10 um to 600 um completed in less than 600 us). After the fiber segment is activated, a rapid release of greater than 2% original length is imposed. The fiber goes "slack" and begins to take up the length change. It is assumed that during this period, the fiber is contracting at its maximum veloctiy This procedure is repeated for several values of length change and magnitude of imposed length change is plotted against time to take up slack with the slope being the maximum contraction velocity (5). In addition, the cacium sensitivity of the regulatory proteins can be determined by activating the fiber in different concentrations of calcium. In general, a sigmoid relationship between calcium concentraction and force is obtained (12).

Histological Experiments

The single fiber segment is removed from the chamber and processed histologically using the methods of Brooke and Kaiser (3) to yield fiber type. The fiber type distribution within the biopsy and the selective hypertrophy/atrophy are determined using a digitizing pad and interface using the methods of Brooke and Engel (2).

RESULTS

The contractile properties of a single skeletal muscle fiber from the tibialis anterior muscle of the frog (*Rana pipiens*) have been determined during fixed-end tetani and during tension transients after rapid release. The data indicate that the time course of changes in different regions of the single fiber can be monitored in real-time We have observed that during fixed-end tetani, contractile behaviour of different parts of the fiber are qualitatively different. These data have been discussed in terms of the mechanism of force generation in skeletal muscle by Lieber and Baskin (6).

DISCUSSION

A technique is presented which allows objective characterization of the force-generating ability of a single skeletal muscle fiber segment. This technique is minimally invasive to the patient as all muscle is taken using either needle biopsies, or typical biopsy methods during surgery. It is completely noninvasive to the muscle fiber segment.

The classic experiments of Buller et al. (4) demonstrated that neural input to a muscle drastically effected its histological and contractile characteristics. Recently, Sreter and colleagues have further investigated this phenomenon (10) and shown that impulse activity to the muscle may itself determine the characteristics of the muscle. This interaction between muscle and nerve can therefore be exploited to determine the integrity of peripheral neuromuscular function which may be an indication of central nervous system health. The application of this technique to the victim of central lesion is underway.

REFERENCES

1. Bergstrom, J. (1962). Muscle electrolytes in man. *Scand. J. Clin. Lab. Invest.* 14(suppl. 68):1-110.

2. Brooke, M.H. and W.K. Engel (1969). The histographic analysis of human muscle biopsies with regard to fiber types. 2. Diseases of the upper and lower motor neurons. *Neurology* 19: 378-4

3. Brooke, M.H. and K.K. Kaiser. (1970). Muscle fiber types: How many and what kind? *Archives of Neurology (Chicago)* 23:369-4

4. Buller, A.J., J.C. Eccles, and R.M. Eccles. (1960). Interactions between motorneurons and muscles in respect of the characteristic speeds of their responses. *J. Physiol.* 150:417-439.

5. Edman, K.A.P. (1979). The velocity of unloaded shortening and its relation to sarcomere length and isometric force in vertebrate muscle fibres. *J. Physiol.* 246:255-275.

6. Lieber, R.L. and R.J. Baskin. (1983). Intersarcomere dynamics of single skeletal muscle fibers during fixed-end tetani. *J. Gen. Physiol.* submitted

7. Lieber, R.L., R.J. Baskin and Y. Yeh. (1983a). The Effect of beam and fiber diameter on sarcomere length measurements in single skeletal muscle fibers. submitted to *Biophys. J.*

8. Lieber, R.L., K.P. Roos, B.A. Lubell, J.W. Cline, and R.J. Baskin. (1983b). High speed digital data acquisition of sarcomere lengths from isolated skeletal and cardiac muscle cells. IEEE Trans. Biomed. Eng. January 1983. (in press)

9. Lieber, R.L. and B.A. Lubell. (1983). Real-time data acquisition of diffraction spectra from contracting skeletal muscle fibers. Proc. Digital Equip. Comp. User's Soc. 9:in press.

10. Sreter, F.A., K. Pinter, F. Jolesz, and K. Mubachi. (1982). Fast to slow transformation of fast muscles in response to long-term phasic stimulation. Exp. Neurol. 75:95-102.

11. Wood, D.J., J. Zollman, J.P. Reuban, and P.W. Brandt. (1975). Human skeletal muscle: Properties of the "chemically skinned" fiber. Science 187: 1075-1076.

12. Wood, D.S. (1978). Human skeletal muscle: Analysis of Ca regulation in skinned fibers using caffeine. Exp. Neurol. 58: 218-230.

Address for correspondence:

Richard L. Lieber, Ph.D.
Department of Orthopedic Research V-151
V.A. Medical Center
3350 La Jolla Village Drive
San Diego, CA 92161

NERVE REPAIR AND EVALUATION

Gordon S. Abraham and Vincent R. Hentz, M.D.

Rehabilitation Research and Development Center
Palo Alto Veterans Administration Medical Center

Department of Plastic and Reconstructive Surgery
Stanford University Medical Center

ABSTRACT

The lack of objective methods for assessing the extent of nerve injury and regeneration compels physicians to rely on subjective criteria in making clinical decisions regarding type and timing of care; it also hampers the search for better methods of nerve repair. These are significant problems since present methods of peripheral nerve repair, even those employing modern microsurgical techniques, rarely result in regeneration sufficient for full functional recovery. Preliminary results of a parallel investigation of surgical repair techniques and methods for evaluating functional regeneration are presented.

INTRODUCTION

Following injury to a peripheral nerve, the length of nerve distal to the injury undergoes Wallerian degeneration and leaves an inactive conduit of connective tissue and axonal debris [1]. The proximal segment sprouts and grows through the juxtaposing axonal conduit, ideally regenerating to its associated end organ (sensory receptor or motor endplate). In most cases of nerve injury there has been a disruption to the surrounding tissue causing the the axons to no longer align with their associated conduits. In these cases the axons no longer regenerate through their original conduits and likely make connections with end organs inappropriate to their function. The surgeon's role in nerve repair is to align the axons with the appropriate axonal conduit across the injury. Due to the small size and large number of axons within a nerve bundle, the alignment can at best only be approximated. Even with appropriate re-connection of the nerve bundle, other complications can arise. The regenerative process may be hindered by random branching and growth directions of the sprouting axons, the ingrowth of scar tissue into the nerve bundle at the repair site may further inhibit regeneration by blocking the elongating axons [1,2].

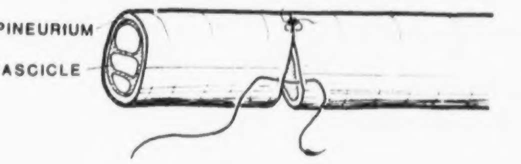
The enhancement of regeneration by the development of more sophisticated surgical alignment techniques, the application of pharmacological agents, or the use of other modalities has been hindered by the lack of quantitative means of monitoring the regenerative process and evaluating the extent of functional reinnervation.

BACKGROUND

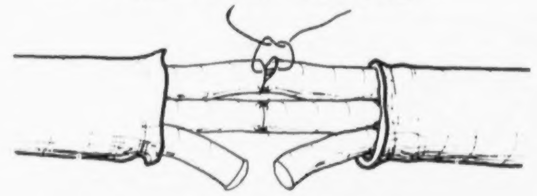
Repair Methods. Two microsurgical nerve repair techniques, epineurial and perineurial suture, are presently in common use. In the epineurial suture (ES) technique, sutures are placed in the perineurium, the connective tissue surrounding the nerve bundle, using surface landmarks for alignment of the axons (Fig. 1a). In the perineurial or facsicular suture (FS) technique, the epineurium is dissected free at the repair site to expose subgroups of axons called fascicles. Sutures are placed through the perineurium surrounding the facsicles (Fig. 1b). Fascicles tend to contain groups of functionally related axons. It is thought that the alignment of axons within a facsicle is not as critical as the alignment of the bulk of the fascicle in order to achieve functionally adequate regeneration [3]. These two techniques, especially the FS technique, suffer the distinct disadvantage of having the suture material (generally 10-0 nylon) introduced in the proximity of the axons. The antigenic reaction to the suture often has deleterious effects on regeneration.

The invasion of scar tissue into the repaired nerve is considered to be a significant barrier to the regeneration [1,2]. A new technique, termed tubulization, utilizes a tube or wrap of biocompatible membrane to re-oppose the ends of severed nerve and to shield the regenerating axons from the ingrowth of scar (Fig. 1c). This method may have other advantages in that it produces total circumferential alignment of the nerve or fascicle, is relatively noninvasive, and contains (and possibly directs) the sprouting axons. The materials used for these repairs have included tubes and membranes of vein, silastic, fibrinogenic material, collagen, and polyglycolic acid (PGA, adsorbable suture material).

(a) EPINEURIAL SUTURE



(b) FASCICULAR SUTURE



(c) FASCICULAR TUBULIZATION

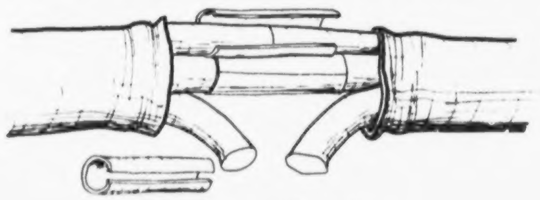


Figure 1. Repair methods.

Evaluation Methods. Histological techniques are the most frequently used quantitative methods of evaluating the extent of regeneration following repair. The fiber diameter histogram (FDH) is obtained by determining the number of axons within specific cross section diameter ranges; the count:diameter data are normally presented in histogram form. The FDH is used to evaluate the number and maturity of the regenerated axons. Longitudinal architecture of the axons at the repair site is a more qualitative means of evaluating repair technique success. Repaired nerves with better organized/aligned axons in the vicinity of the repair are assumed to produce better return of function. Both of the above histological techniques require a section of nerve to be removed, which can only be done in experimental animals at the time of termination. These techniques do not allow the process of regeneration to be continuously followed.

Histologic assessments often correlate poorly with the functional conduction properties of the regenerated axons, it is for this reason that we have applied the distribution of conduction velocities (DCV) approach to evaluate repair methods. The DCV is the electrophysiologic counterpart of the histologic FDH. It is typically plotted as a histogram, showing the relative contribution to the compound action potential (CAP, related to the number of axons) from axons conducting in specified velocity classes. The DCV produces information on the conduction properties of the entire population of fibers whithin the bundle, whereas classical measures of maximum conduction velocity (calculated from the waveform onsets) and CAP amplitude primarily represent only the fastest fibers within the bundle.

The DVC of mixed nerve (both sensory and motor) can be obtained by the "deconvolution" of two CAPs recorded at sites separated by a known distance (2CAP) [4]. The deconvolution technique can be applied to two muscle action potentials (MAP) evoked by stimulation at two sites along the nerve to derive the DCV of motor axons (2MAP) [5,6]. The motor DCV can also be obtained by a collision neurographic technique (CMAP) [7]. This techique employs the interaction of two CAPs evoked by carefully timed stimuli to limit conduction to a small range of conduction velocities. These DCV techniques have also been applied to humans for the evaluation of peripheral neuropathies [7,8].

METHOD

The median and ulnar nerves of thirteen primates, Macaca Fascicularis (Crab-eating monkey), were used as the model for investigating repair techniques. All repairs were performed 15mm proximal to the wrist. Prior to producing the lesion, all nerves underwent at least one electrophysiologic evaluation by the DCV methods described above in order to obtain the preoperative conduction properties of the normal nerve. Motor DCVs of the median and ulnar nerves were produced from MAPs recorded from the abductor pollicis brevis muscle or the abductor minimi digiti muscle, respectively.

Following the preoperative evaluation, the nerves were exposed at the wrist and then transected. The nerves were then repaired by the ES method (14 nerves), or by the FS method after dissection to the fascicular level (16 nerves). Tubulization was done at the fascicular level (FT) using split PGA tubes (17 nerves). Five nerves were not repaired, a 1.0cm segment being removed and submitted for preoperative histologic evaluation.

During the period of regeneration, ranging from 6 to 41 weeks, the extent of regeneration was monitored by the DCV techniques. Two DCVs were obtained by the 2CAP method, one from stimulation at the wrist proximal to the repair, and one from stimulation at the wrist distal to the repair. CAPs were recorded at the elbow and axilla. DCVs of motor fibers that had reinnervated the muscle were obtained by the CMAP and 2MAP methods from MAPs evoked from stimulation at the wrist proximal to the repair site and at the elbow.

At the end of the regeneration period final DCVs were obtained and the nerve was exposed at the wrist and axilla. The nerve at the axilla was crushed to allow recording of monophasic CAPs evoked by stimulation at the wrist proximal and distal to the repair site. The relative areas-under-the-curve of these monophasic CAPs were measured inorder to estimate the fraction of fibers regenerating across the repair [9]. The nerve at the repair site was then removed and submitted for histologic evaluation of FDH and longitudinal architecture.

RESULTS

Changes in the 2CAP DCVs following transection and regeneration indicate an overall slowing in the DCV (Fig. 2a). For these data, the stimulus was applied just proximal to the repair site. Thus the DCVs include all axons, even some which may not have regenerated across the repair site. The slowing of these otherwise healthy axons is thought to be due to degeneration of sensory axons brought about by a lack of afferent stimulation (sensory input) [10]. Motor fibers tend not to undergo this degeneration because of presence of efferent stimulation, but this effect is masked by the large number of slowed sensory fibers.

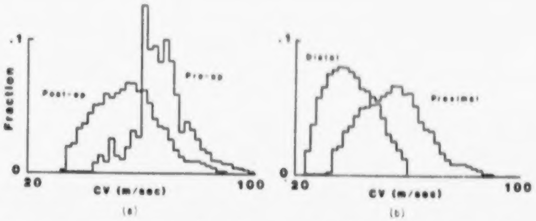


Figure 2. 2CAP conduction velocity distributions (DCV). (a) Preoperative and 30 weeks following epineurial suture repair (post-op). (b) Postoperative DCVs obtained from stimulation just proximal and just distal to repair site. The fraction crossing the repair site was estimated as 33 percent.

The results of including the repair site in the analysis is illustrated in Figure 2b. Differences in the DCVs obtained from stimulation proximal to the repair site and distal to the repair site are brought about by conduction block and focal delays occuring at the repair site. The ratio of the two rectified CAP's areas indicated that 83 percent of the fibers regenerated across the repair site.

Motor DCVs acquired preoperatively and after the regeneration period are shown in Figure 3. These DCVs indicate an overall decrease of fibers but not an overall slowing of the proximal motor fiber population from the range of the preoperative control [10]. The only motor axons which contribute to these results are those which had made a functional connection to the muscle under study.

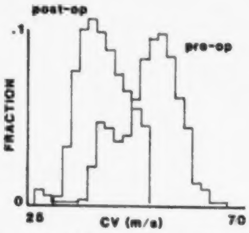


Figure 3. DCVs obtained just prior (pre-op) to, and 29 weeks following (post-op) Perineurial suture repair.

Preliminary analysis of the electrophysiologic data from a small number of primates showed no significant difference in regeneration between the three repair methods. There was a significant difference between the repaired and unrepaired nerve regeneration. Histologic evaluation showed generally better longitudinal architecture of axons at the repair site of nerves repaired with the FT technique than those repaired by other techniques. FDH evaluations have not been completed at this time.

DISCUSSION

The preliminary results indicate no one method to be superior. Further analysis may reveal a slight superiority of one method but it is doubtful that any clinically significant difference will be found.

Whereas the suture repair methods, ES and FS, are widely used by skilled practitioners, tubulization techniques enjoy no such advantage. Likewise the materials used in the FT repairs have not been fully developed. It is possible that FT repairs may prove clinically superior to other methods of nerve repair with the refinement of the physiologic and handling characteristics of the membrane, but owing to the lack of any significant difference in the results with the different repair techniques, it is likely that physical re-alignment techniques are close to optimal.

CONCLUSION

The extent of functional regeneration following a nerve injury is dependent on the type and course of the surgeon's intervention. Present methods of treatment are not capable of producing return of function adequately approximating preinjury abilities. The lack of a clearly superior surgical repair method suggests that other modalities specific to the regenerative process, such as pharmacological agents, must be investigated. The course of treatment is subject to qualitative assessment by the surgeon and is often not clear. To aid the surgeon in directing the course of treatment, methods for evaluating the extent of injury, preoperatively and intraoperatively, must be developed to allow the full potential of the new repair methods to be realized.

ACKNOWLEDGMENT

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REFERENCES

1. Sunderland S. Nerves and Nerve Injuries. Churchill livingston: New York, 1978.
2. Peacock EE, van Winkle W. Wound Repair, 2nd ed. W.B. Saunders Co.: Philadelphia, 1976.
3. Orgel MG, Terzis JK. Epineurial vs. perineurial repair: an ultrastructural and electrophysiological study of nerve regeneration. Plast Reconstr Surg 60:80-91, 1977.
4. Cummins KL, Dorfman LJ, Perkel DH. Nerve conduction velocity distributions: A method for estimation based upon two compound action potentials. In: Dorfman LJ, Cummins KL and Leifer LJ eds. Conduction Velocity Distributions: A Population Approach to Electrophysiology of Nerve. Alan R. Liss: New York, 181-231, 1981.
5. Caddy DJ, Kranz H, Westerman RA. Electrophysiological determination of peripheral nerve conduction velocity distribution. In: Kidman AD, Tomkins JK and Westerman RA eds. New Approaches to Nerve and Muscle Disorders. Excerpta Medica: Amsterdam, 114-129, 1981.
6. Dorfman LJ, Cummins KL, Abraham GS. Conduction velocity distributions of the human median nerve: comparison of methods for study of different fiber populations. Muscle Nerve (in press).
7. Leifer LJ, Meyer MA, Morf M, Petrig B. Nerve-bundle conduction velocity distribution measurement and transfer function analysis. Proc IEEE 65:747-755, 1977.
8. Cummins KL, Dorfman LJ. Nerve fiber conduction velocity distributions: Studies of normal and diabetic human nerves. Ann Neurol 9:67-74, 1981.
9. Rosen JM, Jewett DL. Physiologic methods of evaluating experimental nerve repairs. In: Jewett DL and McCarroll HR eds. Nerve Repair and Regeneration. C.V. Mosby: St. Louis, 1980.
10. Milner TE, Stein RB, The effects of axotomy on the conduction of action potentials in peripheral sensory and motor nerve fibres. J Neurol Neurosurg Psychiatry 44:485-496, 1981.

Rehabilitaion Research and Development Center /153
Palo Alto Veterans Administration Medical Center
3801 Miranda Avenue
Palo Alto, CA 94304

Functional Assessment: Evaluation of a Therapeutic Riding Program

V. Marie Fox, Valorie A. Locricchio-Lawlor and Marvin W. Luttges
Department of Aerospace Engineering Sciences
University of Colorado Boulder, Colorado

ABSTRACT

Objective quantification of the therapeutic benefits of a horseback riding program was attempted. Following the design and fabrication of novel test instrumentation, field tests were conducted. The quantified results from the test device yielded findings which compared favorably to the more conventional clinical impressions of the subjects' parents, therapists and physicians. Horseback riding appeared to be effective therapy and quantification of such therapeutic benefits appears to be an achievable goal.

INTRODUCTION

Therapeutic programs are most often described in terms of healing, reconditioning or reeducation. These efforts are thought to restore the means through which a patient may reasonably expect to lead a fulfilling life. Or, at least, such efforts should provide an identifiable step toward a fulfilling life. Practitioners and patients, alike, try to set and achieve goals which will lead to the desired functional improvements.

Unfortunately, to date, there are few means through which to measure the objective improvement in motor output systems. Diagnosis is difficult. Assessment of different therapeutic strategies is extremely difficult. And, the establishment of small, realistic improvement goals during rehabilitative therapy is almost impossible. It seems clear that better means must be devised to characterize the objective, quantified functions of motor output systems.

This study focuses upon the development of reliable quantification tools to be used in assessing the progress of handicapped persons in a therapeutic horseback riding program. A therapeutic riding program was chosen for several reasons. Riding has been suggested to help reduce spasticity, improve sitting balance and coordination. Indirect benefits have been suggested to include increased social skills and an increased sense of self-confidence. In addition, a riding program is very flexible in accommodating a range of rehabilitation problems.

METHOD

Nineteen participants in the Colorado Therapeutic Riding Center, Inc., riding at High Country Stables, Longmont, Colorado, were the subjects of study in the therapy group. These Ss were 11 males and 8 females, 7-41 years of age. Physical handicaps included cerebral palsy, spina bifida, and varying degrees of hemiplegia. The mentally handicapped Ss included those with mild retardation or learning disorders and ranged to those with profound retardation. Some Ss had additional physical problems such as impaired vision and hearing.

Parents or guardians of each subject were sent information describing the objectives and procedures of the study. Participation was voluntary and Ss were free to discontinue their participation at any time for any reason.

Each subject participated in two 10-minute testing sessions, one before and another after a 2 hour riding lesson. The order of testing was held constant over Ss and test sessions. All tests were not appropriate for all Ss. Questions dealing with psychological factors such as self-esteem, self-confidence, and cooperation were asked intermittently at fixed periods during test administration.

The horses used in therapy were selected because of calm and predictable behavior. Lessons were conducted by a qualified instructor.

Evaluations of the students before and after the six weeks of riding were completed by parents and therapists or doctors. In addition, an assistant to the riding instructor kept a daily log on all of the Ss, recording physical, psychological and social activities of the students.

Recording

Personal data, including body structure characteristics, were recorded by an E on a personal data sheet. Included were measurements of the spinal column from the seventh vertebra (C-7) to the fourth sacral vertebra (S-4). Shoulder lengths were measured from C-7 to the left acromion process and from C-7 to the right acromion process. Tilt of the left shoulder in relation to the right was also recorded. The spinal curvature was determined by pressing a flexible curve along the spinal column. The form of the resulting curve was then traced on a separate data sheet. Psychological assessment responses were recorded by an E on the S's personal data sheet.

Data Analysis

Data were divided into five major categories for analysis. Balance and coordination tasks were analyzed for stability and accuracy. Strength measures were analyzed for increases or decreases. Posture, using spinal curve measures, was examined in terms of straightness. Psychological scales were used to index attitude changes.

Each person served as his/her own control. All scores were normalized within Ss before grouping the data. Data analyses were done using group means to compare before and after riding performance.

The postural analyses were done by comparing the Ss spinal curve measure to a model of the spine depicting normal posture described by Kendall, Kendall and Boynton (1972). A description of the cervical, thoracic and lumbar section of each curve was given in terms of tilt, lordosis and kyphosis. A scale of 1-7 was used with 4 representing "normal" amounts and direction of curve, 1 depressed curvature and 7 accentuated curvature.

Psychological effects also were based on pre-lesson data compared to following lesson data. Questionnaires also were analyzed for changes occurring over a six week period of time. Physiological and psychological data were evaluated separately, and then comparisons between the categories were made.

Apparatus.

The basic test device was designed and built within the Departmental shop facilities. It consisted of a symmetric balance beam supported by a bearing affixed to an aluminum base. Behind the bearing, the shaft of the balance beam was clamped to the slider of a high quality, wire-wound potentiometer. All movements of the beam were translated into variations in electrical resistance. The device was constructed such that at the end of the maximum motion of either arm of the beam a heavy spring was engaged. The spring, loaded in compression, provided for strength testing. Before the arms of the beam engaged these springs, the device provided a means for balance and coordination testing.

A metal pointer attached at the fulcrum point of the beam provided visual feedback for the Ss. It moved against a scaled background which denoted both a central balance point and measured deviations to the left or right. A backlighted floral display was illuminated during periods of balance. In addition, a variable voltage originating from the potentiometer changes was used through a voltage-frequency converter to yield auditory feedback. A balanced beam resulted in a slow pulsing sound while deviations from the balanced position resulted in progressively higher frequency sounds (Fig. 1). All output from the balance beam potentiometer was recorded on an Esterline-Angus 575 X-Y record using a built-in time base.

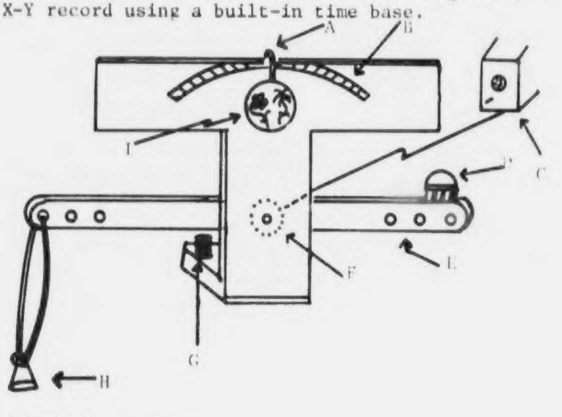


Fig.1 Apparatus.
A.Pointer B.Scale C.Speaker D.Brush
E.Balance Beam F.Potentiometer
G.Compression Spring H.Stirrup
I.Floral Display

Other equipment used included the following: a T-square with a bubble level for measuring the S's shoulder tilt, a flexible curve for measuring the S's spinal curve, a tape measure for measuring spine and shoulder lengths, stirrups with adjustable leathers for use in the Legs:Strength and Balance/Coordination tasks.

Tasks

The tasks described here are listed in order of presentation to the S.

Hands/Arms:Balance/Coordination. The first task, described as a balance and coordination task, required the S to hold the reins as in riding. A small horse figure connected indirectly to the reins moved to the right or left depending on the direction in which the S moved the reins. The S was told to steer the horse as straight as possible. Each 10 second trial was begun by starting the horse to the side of the target area (once each from the left and right sides) and requiring the S to bring it into line.

Hands/Arms:Strength. For this strength test the S's hands were put into the handstraps of horse brushes. The brushes were directly connected to the beam and indirectly to the compression springs. The S engaged the spring attempting to depress it as much as possible during the 5-second trail period. Two strength trials were done with the left hand and then two trials with the right hand.

Hands/Arms:Balance/Coordination. Each S was instructed to use the hands to bring the pointer into the target zone. One trial required the S to move the pointer from the right side of the scale to the center target area and hold it there for 10 seconds. On the second 10-second trial, the S began with the pointer to the left and proceeded as above.

Legs:Strength. For those Ss who had some ability use their legs, the following tests ensued. As in the arm strength test, pushing the stirrup caused the lever to engage the spring. The S was encouraged to maintain the hardest force possible for the remainder of the 5-second trial. Two trials were done using the left foot and then two trials using the right foot.

Legs:Balance/Coordination. The feet were again placed in the stirrups as described above. Coordination and balance were evaluated by S's attempts to maintain a target position. A balanced position was to be held throughout the 10-second trial. The task was repeated with the pointer starting once from the left and once from the right.

Ss were thanked for their participation and helped to their riding lesson or to the transportation area for the trip home.

The data collected during balance and coordination tasks were quantified individually and then pooled for an overall assessment of the effects of riding.

Following the typical 90-120 minute riding lesson, the ability of subjects to exhibit accurate positioning of the balance beam had increased by 18.6% compared to the ability tested prior to riding. Control studies had indicated that a practice effect would have accounted for no more than 4% improvement. Also, these performance indices were collected prior to a therapy session (6 week duration) and after a session, so the subjects had probably achieved asymptotic practice benefits prior to many of the oral tests.

Using the raw data obtained during the same tests, it was possible to quantify response stability. Responses which moved in a steady fashion to the balance position and then remained there were considered indicative of stability. In contrast, responses which moved hesitantly with direction reversals were considered unstable as were responses which continued to deviate from the balance position. Stability quantification revealed a 7.2% increase immediately after riding. This measure was relatively immune to practice effects as determined in earlier control studies. Also, this change includes individual instances in which stability of response dramatically decreased.

When the subjects were tested for strength, both before and after a riding lesson, we assumed that fatigue might play a major role in the scores obtained. Surprisingly, the pooled arm strength measures showed a 7.8% increase following riding. The legs, used more extensively than the arms during riding, showed a 8.0% increase. The range of differences in pre- and post-riding strength varied considerably between individual subjects but was quite reproducible for individual subjects.

The evaluations of stature obtained in seated subjects led to reproducible measures of spinal curvature and lateral symmetry. The data were subdivided into cervical, thoracic and lumbar representations. Following riding, most subjects sat straighter and exhibited more normal spinal curvature than in tests conducted prior to riding (Fig. 2). Although no objective index was available for such an impression, the experimenters associated many of the above improvements with apparent relaxation following the riding lessons.

The simple evaluations of cooperation, tension, self-concept and self-esteem led to favorable, positive responses both prior to and following riding.

One other piece of our findings deserves note. The home assessments prepared by parents, guardians, therapists and physicians revealed a dramatic increase in the subjects' physical abilities. Over the typical 6-8 week therapy session, these observers indicated that the subjects exhibited a 30% increase in physical ability. These assessments of course, reflect subjective impressions. But, the correlation with objectively recorded improvements in balance, coordination, stability and strength is not easily ignored.

DISCUSSION

The 30% average increase in the subjects' physical abilities reported by physicians, therapists and parents was substantiated by the quantitative analysis of pre- to post-therapy tests. These objective data reflected a 7.8% increase in arm strength, and 8.0% increase in leg strength and an 18.0% improvement in posture indices. Posture improvements were not only reflected by objective results, but also were dramatically obvious in subjects' appearance.

This preliminary testing confirms horseback riding as an effective therapy. Quantitative measures confirmed pre- to post-therapy benefits and the overall relaxation.

Perhaps the most important gains for participants in programs of this type are the increases in self-confidence, acquisition of new skills, and the chance to interact with others.

In conclusion, the test equipment designed and built for the purpose of objectively quantifying the effectiveness of therapy programs gave both reliable and valid measures. It appears that instrumentation of this type can aid in both diagnosis and measurement of motor system characteristics. Such aid should be invaluable to most therapy programs and could be designed in a robust fashion to accommodate a variety of needs.

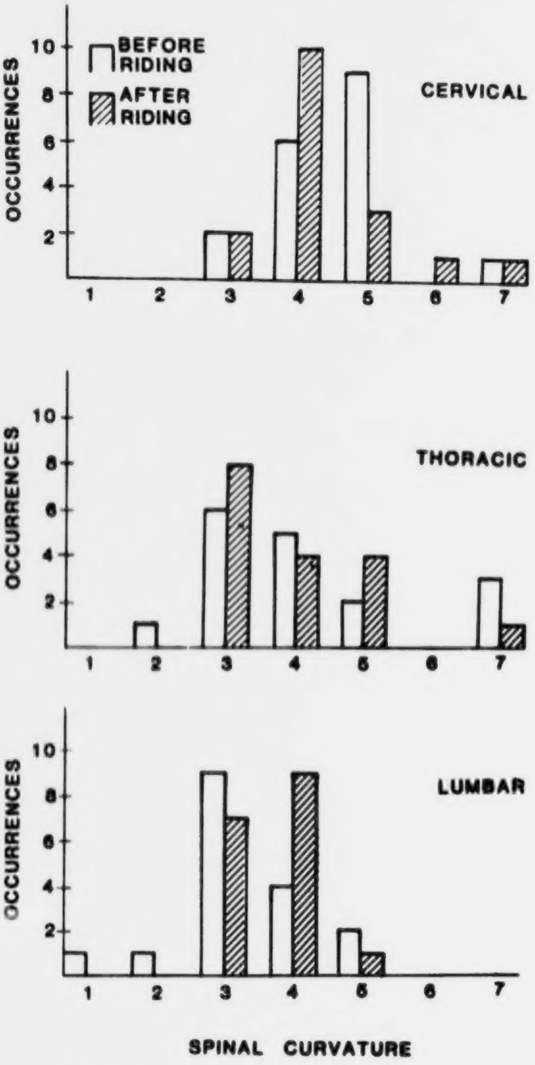


Figure 2. Assessment of Spinal Curvature

REFERENCE

Kendall, H.O., Kendall, F.P., and Boynton, D.A. Posture and Pain. Baltimore, Williams and Wilkins 1972.

ASSESSMENT OF NEURAL STRATEGIES FOR THE PROCESSING OF SOMATOSENSORY CUES DURING VOLUNTARY MOVEMENT

C.C. Boylls, RRanD Center, VA Medical Center, Palo Alto
R.W. Angel, Dept. Neurology, Med. Sch., Stanford University
R.L. Rodnitzky, Dept. Neurology, Med. Sch., Univ. of Iowa
M. Weinrich, Dept. Neurology, Med. Sch., Stanford University

Introduction

Skilled voluntary movement depends critically upon the appropriate use of somatosensory feedback by both low-level reflex circuitry and conscious perceptual mechanisms. Nevertheless, many common diagnostic protocols applied to sensorimotor disorders rely solely on the reflex responses or perceptual reports of individuals who are not trying to move! This paradox might have little assessment significance if the qualitative attributes of reflex and perceptual mechanisms remained unaltered by voluntary motor outflow-- but there is growing evidence to the contrary (refs. 2-5). It may in fact be that certain types of sensorimotor dysfunction owe themselves to the aberrant "tuning" of reflex and perceptual mechanisms during voluntary movement.

In the present study we demonstrate the effects of differing voluntary tasks upon the outcome of two sensorimotor assessment procedures: The first examines properties of the short-latency reflex linkage between antagonistic muscles at the elbow, while the second looks at correlations between somatosensory evoked potentials (SEPs) and motor perception. Further details of our findings are available elsewhere (refs. 1,2).

Methods

Both assessment techniques involve the delivery of brief torque perturbations (3-8 N-m applied for 20 msec) that tend to flex or to extend the elbow of a seated subject whose abducted arm is supported by an instrumented cradle (Angel, Rodnitzky, and Boylls, in preparation). Surface EMGs (rectified, filtered) are obtained from the antagonistic biceps/triceps muscle pair, as are SEPs recorded over the contralateral somatosensory cortex (precentral sites recorded relative to postcentral, precentral positive). Experimental protocols entail the presentation of fixed-amplitude elbow perturbations, at random times and directions (flexion/extension) while subjects (6 male, 2 female, ages 19-59, with no evidence of neurological deficiency) perform those types of voluntary activity that lead to the following outcomes:

Results

(a). Reversal of the reflex linkage between antagonistic muscle pairs as a function of voluntary motor performance

Short-latency reflex responses in paired antagonists are usually thought to be governed by Sherrington's principle of reciprocal innervation, wherein the reflex contraction of one muscle is accompanied by relaxation of its opposite. We find, however, that if a subject is instructed to maintain elbow position against an external, static torque opposing either flexion or extension, then coactive, rather than reciprocal responses appear in the biceps and triceps following a momentary increase in that torque. Thus, for example, in Fig. 1 (average of 16 trials) a static external load (5 N-m) opposing biceps is momentarily increased-- prompting short-latency excitatory responses in both biceps and triceps. By contrast, we are also able to produce "standard" Sherringtonian reciprocal activation if we replace the external, static load with "loads" produced solely by contraction of the antagonistic muscles themselves. This can be accomplished by instructing the subject to coactivate both biceps and triceps (we use biofeedback to achieve this performance reliably). A momentary stretch of biceps then evokes reciprocal biceps/triceps responses (Fig. 2). In summary, therefore, a subject's voluntary motor intentions can result in considerable qualitative alteration of reflex reactions to somatosensory signals.

FIG. 1 Pulse Load of Biceps

(with background load opposing biceps)

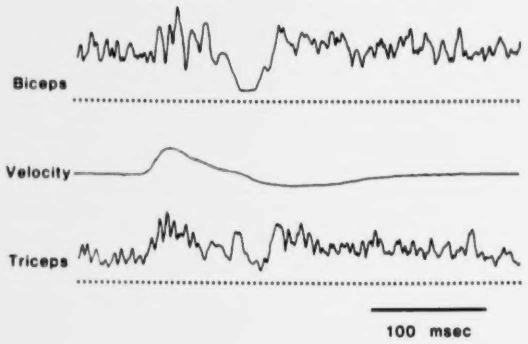
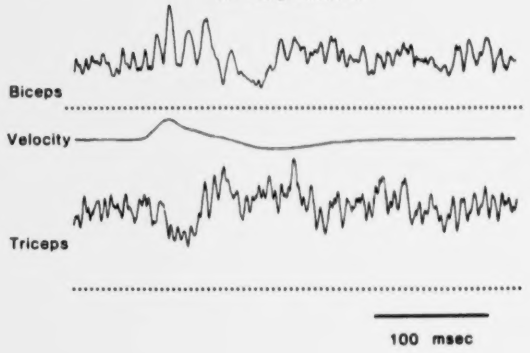


FIG. 2 Pulse Load of Biceps

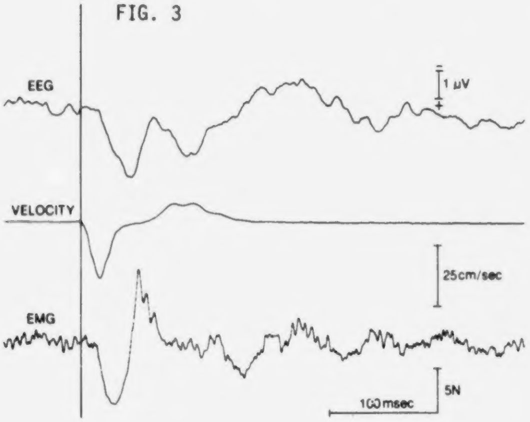
(no background load)



(b). Correlated changes in SEP amplitudes and sensorimotor perception in the presence of voluntary movement

Somatosensory cues that trigger the reflexes discussed above are also, of course, open to perceptual interpretation by our subjects. We thus have explored how subjects experience elbow perturbations delivered in the presence or absence of voluntary movement; and we additionally have compared those interpretations with the properties of SEPs that perturbations generate. In brief, when asked to report orally on the direction ("flexion" or "extension") of a random elbow perturbation, subjects can do so with high accuracy, provided that they are instructed simply to maintain a fixed elbow position. They likewise exhibit prominent SEPs, whose peak deflections are achieved at latencies varying between 56 and 98 msec following the perturbation (mean 71 msec; S.D. 12 msec). Fig. 3 typifies such an SEP (average of 16 trials; stimulus is a brief reduction of a static load opposing biceps). However, when the same subjects are asked to perform voluntary elbow flexions or extensions at moderate velocity, the ability to report on perturbation direction can fall to chance levels. At the same time, SEP amplitude is greatly diminished (Fig. 4). This apparent correlation between perceptual accuracy and SEP amplitude has proved statistically significant ($p < 0.05$) in 4 of 8 subjects. Similar results are obtained when elbow perturbations are triggered by the onset of voluntary EMG-- i.e., prior to the start of any actual movement. Thus, the mere appearance of a voluntary motor command can have immediate and significant implications both for transmission in somatosensory pathways and for sensorimotor perception itself.

FIG. 3



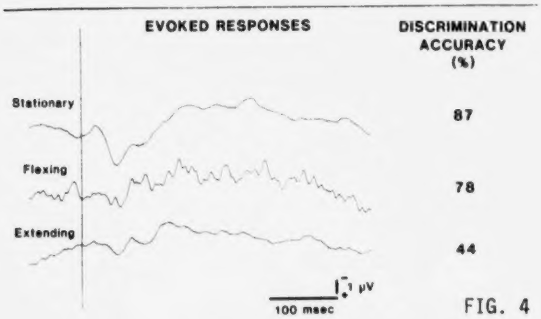


FIG. 4

Discussion

Assessments of short-latency reflexes, SEPs, and somatosensory awareness are an integral part of neurological diagnosis and treatment evaluation. But as the present results illustrate, a nervous system attempting voluntary movement can make substantially different use of somatosensory information than one which is quiescent. In that respect, our observations reinforce numerous other studies ranging from electroreception in fish to saccadic suppression in humans (Angel, Rodnitzky, and Boylls, in preparation). The findings also raise questions about the extent to which certain neurological disabilities owe themselves to subtle deficiencies in the utilization (or, for that matter, rejection) of somatosensory signals during voluntary activity. Work recently begun with selected populations of the neurologically disabled, using the methods presented here, may possibly help to answer such questions and to refine neurological assessment procedures accordingly.

References

1. Angel, R.W., Boylls, C.C., and Zomlefer, M.R. Short-latency linkage between human elbow antagonists appears reversible through alteration of joint preloading. Neurosci. Abstr. 8, 734 (1982).

2. Angel, R.W., Boylls, C.C., and Weinrich, M. Cerebral evoked potentials and somatosensory perception. Neurology (in press).

3. Angel, R.W., and Malenka, R.G. Velocity-dependent suppression of cutaneous sensitivity during movement. Exp. Neurol. 77, 266-274 (1982).

4. Coquery, J.-M. Role of active movement in control of afferent input from skin in cat and man. In: Gordon, G. (ed.), Active Touch, Pergamon Press (Oxford, 1978).

5. Garland, H., and Angel, R.W. Modulation of tactile sensitivity during movement. Neurology 24, 361 (1974).

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Rehabilitation Research and Development Center
VA Medical Center
Mail Stop 153
3801 Miranda Avenue
Palo Alto, CA 94304

COMPUTER AIDS FOR BLIND AND VISUALLY IMPAIRED PERSONS

Daniel N. Van Horn
Susan H. Phillips

SENSORY AIDS FOUNDATION

ABSTRACT

Sensory Aids Foundation, under a grant from the Projects With Industry section of the Rehabilitation Services Administration is offering a program to expand employment opportunities for physically disabled individuals in computer related jobs throughout the State of California. The number of computer related jobs is expanding rapidly in business, industry and government. Several computer-based sensory aids used by handicapped employees are presented in this paper. Examples include the VersaBraille and the ARTS Large Print Terminal.

INTRODUCTION

Sensory Aids Foundation is a non-profit corporation that directs and manages a variety of programs aimed at increasing the independence and employment opportunities of handicapped persons. The Foundation which began in 1975, originally focused on job development services for blind and visually impaired persons. In 1979 Sensory Aids Foundation received a Projects With Industry grant (PWI) from the Rehabilitation Services Administration to expand employment development services to persons with hearing, vocal and orthopedic disabilities. This continuing Project emphasizes employment in computer related occupations. A contract with the California Department of Rehabilitation has provided continued employment services and technical consultation to blind and visually impaired persons. Since the beginning of these programs over 365 disabled persons have been assisted in obtaining or maintaining competitive employment.

Many new employment opportunities are becoming available because of the rapid changes in technology. For qualified disabled people to enter and work competitively in these new areas, sophisticated aids must often be utilized. Microprocessor based aids are capable of providing alternative computer input and output modes for blind, non-vocal and orthopedically disabled persons.

We are in the midst of a revolution, and though that is obvious to most of us, blind people are just beginning to find this out. In order to keep pace with the rest of society, blind people must have access to the same technology. Computers need to be made so that they are easily compatible with speech synthesizers and soft copy braille systems. Software needs to be written so that it can be easily used with this equipment. Some blind people are already beginning to explore the technology available and how it can assist them in competitive employment positions. The technological advances through microprocessors, computer chips and software capabilities offer incredible potential for the job market of disabled people.

BACKGROUND

Recently, Sensory Aids Foundation was asked to assist Security Pacific Bank in modifying a staff support position in their Marketing Department for a blind employee. The process began with a thorough interview with the blind person involved to determine her preferences in accessing information. In this case she was a competent Optacon user, but found using the Optacon inefficient in terms of productivity while working on a computer screen but adequate for hard copy. She also had excellent braille skills and enjoyed reading and writing in braille. After being exposed to synthetic speech through a talking terminal, she was unenthusiastic about using it as a means of accessing large amounts of database information, but interested in other possible applications. In addition, we discovered that she had excellent key board skills, typing at 70 wpm error free.

The next step in the process was to explore the tasks required for the job. There were three major aspects to the job: typing correspondence and reports, answering incoming calls on a thirty button telephone and updating marketing information using an Apple II microcomputer.

MATERIALS AND METHODS

Sensory Aids Foundation (SAF) consulted with the Rehabilitation Engineering Center at Smith-Kettlewell Institute of Visual Sciences and Tom Fowle agreed to build a talking monitor to substitute synthetic speech for the standard visual cues on the thirty button call director. The designing of this device is in progress at this time and as conceived it will consist of the following components:

1. An overlay with thirty light sensors to monitor the status of the thirty lines on the call director.
2. A National Digitalker microcomputer with custom software and three control buttons.

When in use this system will provide the user with voice output information on the status of calls. When a call comes in the talking board will announce the column of the appropriate line by letter and the corresponding row by number (e.g. B4 for a call coming in on the line whose button is in the second column, fourth row.)

There will also be control buttons which command the device to vocally list all calls on hold and all lines which are in use at a given time.

Sensory Aids Foundation has provided a VersaBraille on loan to assist this person in producing letter perfect copy and in accessing the Apple II at the worksite. Using the VersaBraille connected to either of the two printers available she is able to generate reports and correspondence and do her own proofing and editing.

The Apple II and the VersaBraille were interfaced with a modified cable constructed by Jonathan Schwartz of NASA Ames Research Center and a super serial interface card. This allowed the user to monitor information from the screen in braille and input marketing data to the system via braille. This interface allows the user much more rapid access to information than would the use of her Optacon.

Sensory Aids Foundation also works with clients in certain employment situations to evaluate existing equipment. Such was the case of a Senior Statistician at Woodward-Clyde Consultants who began losing his vision as a result of Retinitis Pigmentosa. We have an original model of the ARTS Associates Large Print Video Terminal (LPVT) which we loaned to him for a period of nine months. The purpose of the loan was to enable him to evaluate the effectiveness of the terminal in performing his job tasks. After nine months of using the LPVT he confirmed what had been relayed to us by a previous low vision user who was working as a computer programmer for Spreckles Sugar.

The value of the LPVT for this gentleman was in the size of the video display tube. The large screen by virtue of its size alone allows for larger print and more information on the screen However, there are some major drawbacks to the first model of the LPVT. The terminal has three user selectable sizes. The standard character size is 1/4" in height. The intermediate size is 3/4" in height with no corresponding increase in width. Both users found this long, thin conformation extremely difficult to read and never used the intermediate size. The largest character size is 1 1/2" with a corresponding increase in the width of the characters. While information was easy to read for both users in this mode, the amount of information on the screen at any given time is extremely limited and you are unable to see a complete line at once. In addition, the terminal does not have scrolling capabilities while in the large print mode which makes for awkward and inefficient use of the system. The Senior Statistician uses a terminal regularly in doing simulation programming and is currently using bioptic lenses to monitor the VDT's at Woodward-Clyde. He and the staff at SAF are awaiting the arrival of Visualtek's new large print system in the marketplace to determine its effectiveness for his job tasks.

career areas is increasing.

We must continue to evaluate each situation individually and determine the appropriate aid for a particular person in a particular job. There is no easy answer to making a job accessible to blind and visually impaired people. What it takes is a careful and thorough analysis of job tasks and an individuals functional abilities. Then armed with this information the rehabilitation team can interface the individual's skills with the job tasks using existing aids, modifying equipment at the worksite or developing a special device to solve unique problems.

REFERENCES

1. Phillips, Susan H. and Russell, Yvonne S "Employment Applications of Computer Related Sensory Aids for Blind and Partially Sighted Persons", Proceedings, Thirteenth International Conference on System Sciences, January 1980; and Journal of Medical Systems, vol. 4, no. 2, 1980.

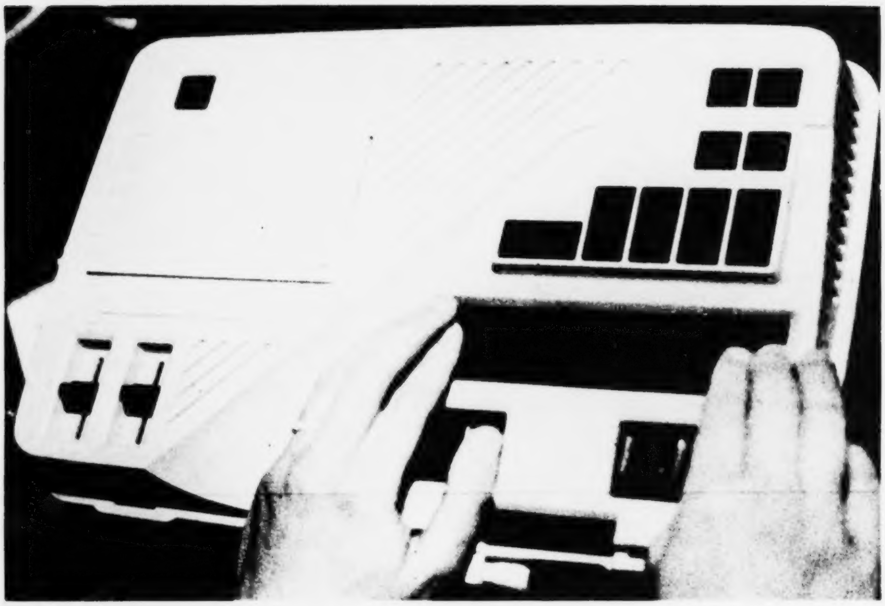
2. Sensory Aids for Employment of Blind and Visually Impaired Persons: A Resource Guide Compiled by Sensory Aids Foundation, published by American Foundation for the Blind, New York, 1978.

3. Phillips, Susan H. and Russell, Yvonne S. "Employment Applications of Computer Related Sensory Aids for Hanciapped Persons", Proceedings of the Fourth Annual Conference on Rehabilitation Engineering, August 1981

Sensory Aids Foundation
399 Sherman Avenue
Palo Alto, CA 94306

LPVT V.2
ER SYS

ARTS TERMINAL



VERSABRAILLE

Daniel N. Van Horn
SENSORY AIDS FOUNDATION
399 Sherman Avenue Suite 12
Palo Alto, CA 94306

PRELIMINARY DESIGN OF A PAPER MONEY RECOGNITION DEVICE FOR THE VISUALLY IMPAIRED

JAMES D. (JIM) SULLIVAN

IMPROVED PETROLEUM RECOVERY, INC.

ABSTRACT

This paper describes some preliminary work toward the development of a portable microprocessor-based device for the recognition of different denominations of American paper currency; the device would detect whether or not a bill is counterfeit and, if not, would determine the denomination of the bill. A voice synthesization chip would be used to output the bills validity or value determination so that the visually impaired would be able to make monetary exchanges (such as purchases, check cashing, etc.) without depending on the eyes of others.

INTRODUCTION

One of the many obstacles to a normal life for the visually impaired is the inability to determine for themselves the denomination of different values of paper currency bills. In paying bills, purchasing merchandise, or any other monetary transaction in which cash may be exchanged, the blind must depend on the honesty of those involved in such an exchange.

Various schemes have been discussed in the past that would allow a blind person to determine what value a bill had. Braille markings as well as different sizes or shapes for paper currency of different values are some of the ideas that have been looked into. For a variety of reasons these techniques do not appear to be a practical solution to the problem.

This paper describes an alternative approach to this problem. It has the following advantages: (1) no modifications are necessary to present, past, or future currency (modifications which might require a great deal of federal political action and would probably be expensive to implement and maintain); (2) the device would be compact and portable; (3) the device would be relatively inexpensive to buy; and (4) built with microprocessor-based electronic circuitry, the device would be highly reliable and accurate.

The device being discussed will now be described in greater detail. There are three basic components of the device in the approach described here. These components are: (1) an optical scanning input system; (2) a microprocessor which would drive the optical scan, perform the bill recognition function, and control the output unit; (3) an audio output microprocessor.

A description of the method in which the device would function will now be given. A bill would be placed inside the device, which would be battery operated and about the size of a paperback book. The device would be activated by a push button. The optical scan would be initiated under the control microprocessor; the scan would compare the optical image against a read only memory (ROM) which contained electronic images of currency in usage. If a mismatch with one bill in memory occurred, the control microprocessor would proceed to the next bill image and the next, if necessary, until either a match occurred or until all bill images in memory had been compared against the test bill. If a match occurred, the control microprocessor would then drive the voice synthesization microprocessor and it would produce an audio output that would notify the device user of its determination; if no match occurred between test bill and all bill images in the memory, the control micro would similarly drive the voice micro notifying the user of this determination.

DETAILED DISCUSSION

The brief description of the system operation given above will now be given a more expanded treament. Again, there are three basic components of the system: (1) the optical scanner; (2) the recognition control micro; and (3) the audio synthesizer output micro. For a more general and comprehensive background on microprocessors, the reader is referred to items (1) and (2) in the references. Each system component will now be given an individual discussion.

Optical Scanner

The optical scanning unit could be any one of several devices that are currently available. These devices are used for different applications at this time, but have the necessary capabilities for the device described in this paper. In order to protect patent rights of this device and because the particular device is somewhat dependent on the recognition control component, of which only one type will be discussed in this paper, the optical scanning component will not be discussed further here.

Recognition Control Unit

The recognition control unit would be activated by a push button on the outside of the device case. The control unit would then be turned on and it would initiate the optical scan. The inserted bill may have been in one of four different positions; each optical input would be converted to a bit, based on its color intensity, and compared against a bill image in memory. The front and back of the commonly used bills (one, two, five, ten, twenty, fifty and one hundred) would be stored in an ordered sequence in a read-only memory. If the recognition control unit detected a mismatch, the other three possible insertion positions would be checked by proceeding through the ROM appropriately. The suggested scanning sequence is: (1) forward through the front side of the ROM current bill image; (2) backward through the front side of the ROM current bill image; (3) forward through the reverse side of the ROM current bill image; and finally (4) backward through the reverse side of the ROM current bill image.

It should be remarked that adjustments must be made for such items as: (1) worn, torn, and less than "mint" condition bills; (2) slight imperfections that occurred during printing, as example, incorrectly centered printed images; and (3) the serial numbers which distinguish each noncounterfeit bill. In order to keep this discussion brief and, again, to protect patent rights the techniques for handling these situations will not be discussed further here.

Returning to the mainstream of this discussion, either a match will be detected at the end of one of the four comparison passes or else it will not be; if it is a match, then the opposite side of the bill is compared against the ROM section either forward or in reverse sequence dictated by the first match (obviously once the position of one side of the bill is determined, so is the positioning of the other side); if there is not a match, then the next bill image in ROM is compared against the actual bill inserted in the device.

The program of the control recognition unit, which is also contained in a ROM, proceeds in the fashion described above, checking one side of the inserted bill for a match, then the other side for a match (if necessary), or proceeding to the next bill image in ROM (if necessary) until either a match for both sides of the bill is detected or until all bill images in ROM have been unsuccessfully compared against the actual bill.

At this point, the recognition unit goes into output mode, drives the audio synthesizer micro and the output either specifies the denomination of the bill or indicates that it could not recognize the inserted bill. The unit then deactivates itself and waits for the next bill to be inserted.

Audio Synthesizer Output Micro

The third and last component of the system is the audio synthesizer output micro. As with the optical scanner, there are several possible choices that would serve here. For example, a phoneme speech synthesizer, such as the VOTRAX® SC-01, or a linear predictive coding (LPC) synthesizer, such as the TMS 5100 or TMS 6100, could be used. The phoneme chip would be the more powerful choice of the two; the LPC choice would be the easier to program. Since the design of such units for this application is relatively straightforward, at least compared to the other two components of the device, it will not be discussed further here. The reader is referred to reference (3) for a comprehensive, yet introductory, discussion of these integrated circuit chips and related interfacing.

ADDITIONAL COMMENTS

Memory Requirements

United States paper currency has the approximate dimensions of 6-1/8 inches (15.5 centimeters) long by 2-9/16 inches (6.5 cm) wide. If scanned at a frequency of 100 bits per inch, this would necessitate about 160,000 bits of storage per bill side. At 50 bits per inch, about 39,000 bits of storage would be needed per bill side; at 64 bits per inch, about 64,000 bits are needed; and at 128 bpi, about 257,000 bits are needed. Seven bills are in relatively common usage in the United States, although some claim the five hundred dollar bill should also be included along with the one, two, five, ten, twenty, fifty, and one hundred.

If the five hundred and larger bills, which are no longer printed (legally), are ignored, storage requirements become (for both sides of seven bills): (1) for 50 bpi resolution, bits needed equals 546,000; (2) for 64 bpi resolution, bits needed equals 896,000; (3) for 100 bpi resolution, bits needed equals 2,240,000; and (4) for 128 bpi resolution, bits needed equals 3,598,000. If an eight-bit microprocessor were utilized for implementation, storage requirements can be stated as: (1) for 50 bpi resolution, about 67K bytes memory are needed; (2) for 64 bpi resolution, 109K bytes memory are needed; (3) for 100 bpi resolution, 273K bytes memory are needed; and (4) for 128 bpi resolution, 439K bytes memory are required. Thus, 50 bpi and 64 bpi resolution are suited to current 8 bit micro (Z-80 for instance); 100 bpi and 128 bpi resolution would probably require a sixteen bit microprocessor for implementation at the time this paper was written.

In addition to the ROM required for storing the bill images, approximately 32K bytes (8 bit bytes) would be needed for the recognition/comparison program. This may seem high considering the simple description of the process involved, but there are expected difficulties in the previously mentioned adjustments which will require considerable code to handle adequately.

There might also be the need for between 5 and 85 K bytes random access memory (RAM). This memory would be needed if the optically scanned information were stored (as opposed to rescanning). Five K bytes are needed for 50 bpi resolution with one side of the bill scanned and stored at a time; 85K bytes would be needed if 128 bpi resolution is used with both sides of the bill scanned and stored. It should be noted that the additional expense of the RAM may well be justified since (1) this would minimize the use of the optical scanner, potentially more sensitive to use than RAM; (2) the optical scan would probably be slower than a memory scan; and (3) it should be easier to make adjustments to data stored in RAM rather than as it is scanned.

Extensions and Options

Although this paper has focused on American currency, there is no reason why the techniques could not be extended in foreign models to handle paper currency from other countries.

A low battery signal system should be incorporated into the system which would bypass the recognition mode once the unit was turned on, send out an audio signal to indicate the batteries should be replaced, and then turn itself off.

A reserve power supply for device use between low battery detection and replacement or an alternate AC power plug would be useful. A private earphone, as well as a small speaker inside the device's case, would also be useful.

Alternate and Additional Recognition Techniques

Other recognition techniques have been, and continue to be, considered either as alternate implementation schemes or as supplemental schemes designed to insure the accuracy of the recognition process. These techniques will not be discussed further here for purposes of brevity.

Other Applications

Devices of this type would also find a ready market in banks, post offices, retail stores, and anywhere else change for bills is made. Obviously this device could be used whenever there is a suspected counterfeit bill. Such devices, if reasonably priced, would virtually eliminate counterfeit currency. In this application, a visual output (such as an LCD or an LED display)would be simpler and less expensive to implement than the previously described audio output component. This application has a huge potential market and would tend to drive the price down for everyone; in particular, the severely visually impaired.

Cost

Cost per device is currently estimated to be about three to five hundred dollars. If hardware cost trends continue and assuming a large market, due to the above mentioned alternate application, the cost could easily decrease to about one hundred dollars. It could even be less, considering a parallel with the pocket calculator.

Related Devices

Bill changers (for one and five dollar bills) are in common usage. Not too many are portable, however, and for obvious practical reasons. The existence of these machines, as well as the micro and memory chips mentioned, demonstrates that the technology required to implement the portable currency recognizer is already available.

Currency counters are also in relatively common usage by banks and similar institutions. It should be noted that state-of-the-art technology for such devices is different from that discussed earlier for bill recognition due to the need for high speed processing; however, such methods are also more expensive at the present time than the recognition method described above due to (1) the need for speed, not a critical factor in the device under discussion; and (2) the requirement for a higher level of electro-mechanical interfacing in currency counters and bill changers.

It should also be remarked that a wealth of standards already exists for such devices. The interested reader should consult, for example, item (4) in the references.

Interfacing

Interfacing has been neglected here for purposes of brevity. Once specific selections for the micros and memory are made, the components should be relatively easy to interface. No specific choices have been made since this device is still in its developmental stages.

The reader is referred to item (5) in the references for further information about interfacing.

CONCLUSIONS

A device has been described which should lead to providing a more independent life for the severely visually impaired. It is hoped that this device, as well as similar ones, will be developed and implemented so that more handicaps can be alleviated through modern technology.

ACKNOWLEDGMENTS

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REFERENCES

1. Microprocessors, Zenith Educational Systems, Unit EE-3401, Heath Company, Benton Harbor, Michigan, Copyright 1977.

2. Cannon, Don L., Ph.D., Assoc. Prof. of Electrical Engineering, University of Texas at Arlington; and Luecke, Gerald, MSEE, Manager, Technical Products Development: Understanding Microprocessors, Texas Instruments Learning Center, Dallas, Texas, Copyright 1979.

3. Voice Synthesis, Zenith Educational Systems, Unit EE-3403, Heath Company, Benton Harbon, Michigan, Copyright 1981.

4. Underwriter's Laboratories Standards (756-8281), February 1982.

5. Staugaard, Jr., Professor Andrew C., Jamestown Community College, State University of New York, Microprocessor Interfacing, Zenith Educational Systems, Unit EE-3402, Heath Company, Benton Harbor, Michigan, Copyright 1982.

For further information concerning this paper contact:
James D. (Jim) Sullivan
Senior Systems Analyst
Improved Petroleum Recovery, Inc.
6440 N. Central Expressway
419 University Tower
Dallas, Texas 75206

TACTILE GRAPHICS DISPLAY

Douglas R. Maure

American Foundation for the Blind

ABSTRACT

The American Foundation for the Blind has designed and developed a new Tactile Graphics Display, which is capable of selectively lifting up to 16,000 pins in a symetrical mechanical matrix. Under electronic control, the display can be used to generate graphics, large print or braille. Its unique design significantly reduces the number of drivers required, resulting in a low-cost device.

INTRODUCTION

The Tactile Graphics Display was developed under a grant funded by the National Science Foundation. It can be configured in single-line, multi-line or full-page displays (Library of Congress standard). Because of its symmetrical dot configuration, multiple alphanumeric fonts, conventional six-dot braille, computer braille and graphics can be generated. Black pins on a white background provide a sharp contrast which enables the partially sighted to use the display, as well as the blind.

BACKGROUND

The present process of generating braille material is bulky and expensive for the following reasons:

1. One page of printed material generates approximately three pages of braille;
2. Heavy-duty paper must be used to prevent the raised dots from being compressed by the finger;
3. Thermoform copies are expensive because of the high cost of reproduction paper (up to 10¢ per sheet);
4. A high percentage of braille material requirements is for limited quantities (less than 100 copies), which makes the automation process impractical;
5. Present high-volume techniques utilizing zinc plates are costly.

The Library of Congress is one of the organizations attempting to reduce these costs, some of which are inherent in the reproduction process and therefore extremely difficult to impact upon these costs. One solution to the problem of cost and bulk is a mechanical device which lifts pins on a single line to generate braille. The braille information is then stored on magnetic tape in digital form and used to control the mechanical display. Companies such as Telesensory Systems, Triformation Systems, Clarke & Smith Industries, F. H. Papenmeier and Maryland Computer Services have attempted to solve this problem by means of computer terminals. Some of the devices provide voice output of computer information as an alternate output.

A major disadvantage of these devices is cost--from $5,000 to $12,000. Mechanical devices used to lift pins range in price from $10 to $20 each, utilizing bimorph drivers (a quartz crystal structure that moves mechanically). A one-line display (40 characters as defined by the Library of Congress) requires 40 x 6, or 240 actuating devices, at a cost somewhere between $2,400 and $4,800.

METHOD

The display is an electro-mechanical device (Figure 1). The latch bar moves horizontally and latches or unlatches pins. The pins rest above or below small protrusions on latch bars. When they rest above the protrusions, they are in the "up" position; when below, they are in the "down" position, providing the latching function. A second group of pins, which also moves with the latch bars, slides into the grooves of the first pins. By moving in the latch bars, these pins engage a lifting mechanism (lift bars and lift bar actuators) which will either lift or lower the pins only in the unlatched row. The following are design features:

1. All raising and lowering actions are positive, driven by the external mechanism;
2. All parts are captive;
3. No return bars are required because the pins are driven either upward or downward;
4. No gravity return is required;
5. No springs or other mechanisms are necessary, thus reducing complexity.

For a 128 x 128 square matrix, 256 drivers are required. Competitive designs require one driver for each pin, or 16,000 actuating devices for a similar display.

IMPLEMENTATION

An analysis was made of the construction of the device in both horizontal and vertical rows. Tolerance analysis indicated that 6-inch lengths of horizontal molding, placed in tandem, would be a superior configuration. The slide bar mechanism was designed to be screwed into the block, utilizing a jeweler's screw, so that individual rows could be assembled and tested before subassembly. A module of 16 x 64 pins was selected to permit ease of repair. Modules of 16 x 64 can be ganged horizontally and vertically to a maximum of 128 x 128 display.

The machining of just one block required 400 cavities, each of which was complex in shape. Breadboard parts were fabricated using a numerically-controlled milling machine. Analysis of

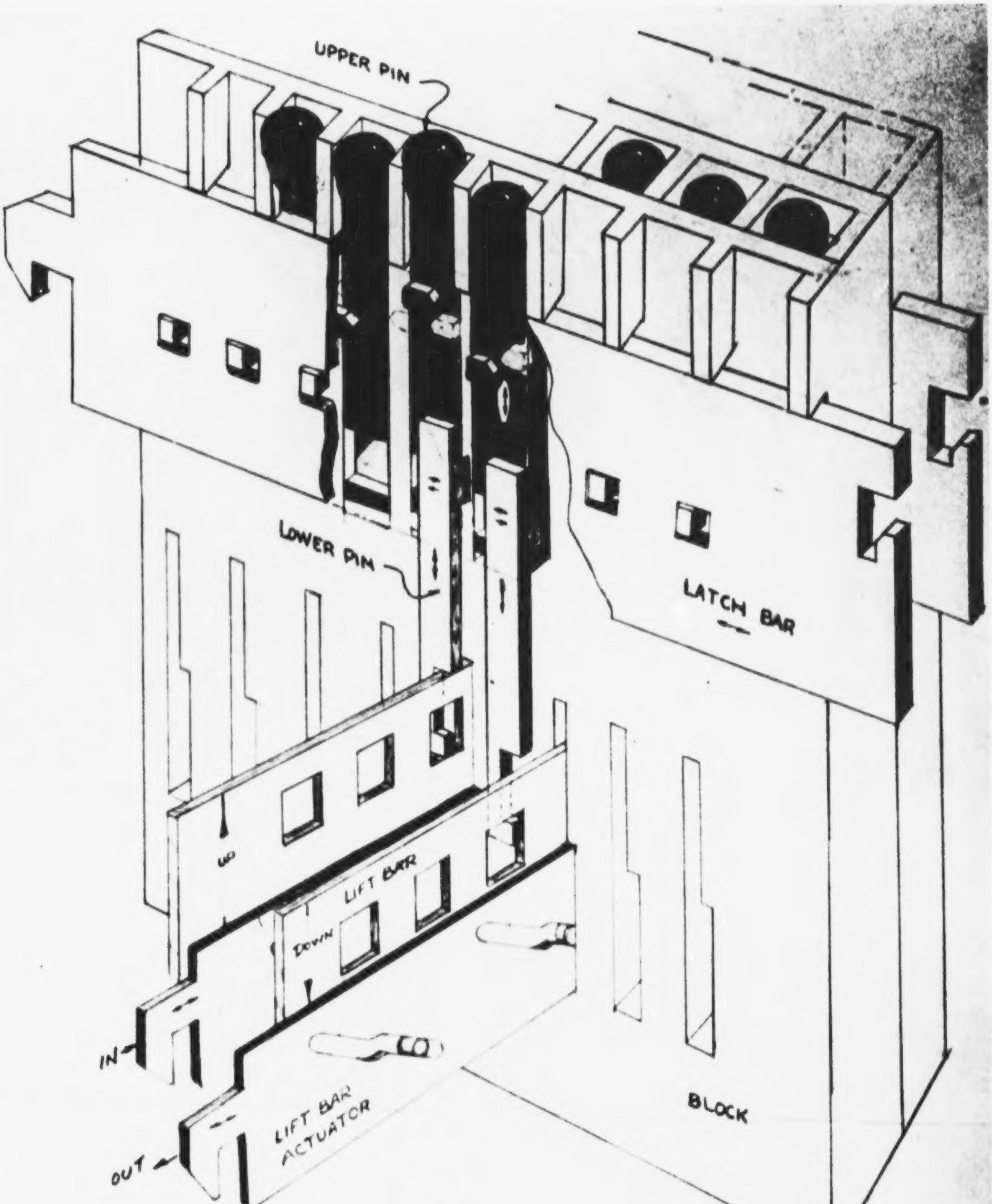
UPPER PIN
LOWER PIN
LATCH BAR
UP
LIFT BAR
DOWN
IN
OUT
LIFT BAR ACTUATOR
BLOCK

FIG 1

a few finished parts resulted in improvements in the pin and latch bar design and increased the horizontal pin movement. It was not practical to machine a complete display because at least 5,000 hours of machine time was required.

The display parts were injection molded. Injection molded parts shrink during fabrication and the amount of shrinkage is difficult to predict and control. Factors contributing to this are:

1. Type of material selected;
2. Mold pressure;
3. Mold temperature;
4. Pressure at which the material is injected;
5. Cycle time of injection molding machine;
6. Configuration of the part.

The design dictated that the match between the block and the slide bar be maintained within .005 inches in 6 inches, although the actual length of these parts did not have to be maintained precisely.

UFE Inc., Stillwater, Minnesota, fabricated the components using molding machines which were computer-controlled, resulting in parts which were within tolerance and repeatable.

Drive Mechanisms

Changing one row of the display is done in the following sequence:

1. Unlatch the row;
2. Raise or lower each individual pin in the row;
3. Latch the row.

The horizontal and vertical displays have different requirements for the drive mechanisms. The horizontal display requires single movement to unlatch a row and single return movement to latch a row. Only one row in the entire display should be activated at a time. The vertical drive mechanism requires a more complex motion. From the neutral position the mechanism is driven forward to lift a pin and backward to lower a pin. This forward and backward motion cams the lift bar actuator either up or down.

Horizontal Drive

Numerous configurations could be utilized for the horizontal drive mechanisms. The least expensive would be a sequential drive, similar to that used in printers, typewriters, etc., where an individual character is printed using a moving belt or a lead screw. Many types of sequential mechanisms would work effectively. Sequential operation would reduce the overall speed of operation but would be by far the simplest and least expensive.

The second technique would be direct drive, i.e., each row or column would have a power solenoid with sufficient energy to latch and unlatch a row. For small displays (single and multiline) this would be the most cost-effective solution.

For full-page displays, small interposing solenoids could be utilized. These interposing solenoids would lift an interposer and a bar would drive only the horizontal row with the engaged interposer. This technique would permit the use of low-power solenoids. Interposers could also be driven by bimorphs for low battery drain. The drive mechanisms designed for the display were of the former type (solenoid interposer). Depending upon application, the other two types of drive may be implemented at a later date.

Vertical Drive

Vertical drive requires a more complex mechanism. One of the paramount requirements is that only one interposer mechanism be used to translate two motions--either forward or backward from neutral. To accomplish this, two counter-moving bars are moved in opposite directions and the interposer engages one of the bars.

Electronics

The electronics necessary to drive the display and interface it to a computer system, or as a stand-alone device, are presently being designed. The implementation utilizes a microprocessor. This report concerns only the mechanical aspect of the display.

CONCLUSIONS

We have constructed and tested an inexpensive display capable of full-page tactile graphics, with dramatic reduction in cost over existing display mechanisms. This low-cost device permits single-line, multi-line or full-page braille, or graphics display.

ACKNOWLEDGMENTS

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Douglas R. Maure
Director
Technological Development Department
American Foundation for the Blind
15 West 16th Street
New York, NY 10011

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THE GALLAUDET REHABILITATION ENGINEERING CENTER FOR THE DEAF AND HEARING IMPAIRED

J. M. Pickett and Raymond J. Trybus
Research Institute, Gallaudet College

This paper describes the background rationales and activities of the Rehabilitation Engineering Center for the Deaf and Hearing Impaired at Gallaudet College. The program of the Center consists of research and development to apply current and emerging technologies for the alleviation and solution of problems caused by deafness, ranging from mild to profound hearing loss. The major focus is on the difficulties in speech communication between deafened and hearing persons.

RATIONALE OF PROGRAM

Our approach focuses on communication by the hearing impaired because we believe that many of their personal and vocational problems would be largely alleviated by greatly improved communication. This is not to say that personal and vocational factors will not play a role in determining the effectiveness of communication techniques, but rather that primary effort on such factors would not have as much innovation-power as research and development for communication.

We also think that the main emphasis in deafness engineering research and development should be on speech communication rather than text-communication. This is because text-communication is based on speech and because of the ease and flexibility of speech; speech is the prime mode. Again, this is not to say that such a Center should not work with the emerging TV text-technologies and message-handling systems, but that such work should not be the major concern at the present time.

Speech Communication and the Problems of Hearing Impairment

Hearing impairments cause deficiencies in speech communication that range from minor to drastically debilitating. The degree of deficiency depends primarily on two general factors: 1) the severity of impairment and 2) the age at which impairment began.

The degrees of hearing impairment extend over a very wide range. Sometimes there is only a slight loss in hearing for tones with no noticeable reduction in speech perception. In many other cases there is a more substantial loss, making communication very difficult, even with a hearing aid, but manageable with care and effort. In still other cases there is a profound deafness which presents a nearly insurmountable barrier to speech communication.

In the latest survey, the number of Americans with significant hearing impairments was approximately 14 million. Of the 6.5 million with "significant bilateral loss" about 50% are elderly. Only a relatively small part of the population, about 450,000 or 0.2%, are afflicted, from very early in life, with profound or total deafness; however, their situation is desperate in that it may totally deny them speaking-access to society and development of adequate language skills.

Many deaf people get sufficient help from wearing a hearing aid. However, while most can hear more sound with an aid, more is not always better, and many find they cannot use what they hear. This is not due to the hearing aid, but due to the abnormal condition of the sensory cells in the ear.

A very special class of hearing impairment is deafness in early childhood. Severe hearing impairment in infancy often causes gross deficiencies in speech communication and in language development. This type of deficit retards all aspects of education of the child.

Communiction by normal-hearing persons depends on the participant's having an inner knowledge of spoken language, i.e., adequate vocabulary and grammar. For persons deafened very early in life this knowledge does not develop sufficiently, even when education is by reading and signs. A major avenue for reasonably normal educational progress would be through optimum development and use of speech communication very early in life. This is our eventual goal for the deaf infant and we believe tht its attainment depends on essential contributions from speech technology.

Speech Technology and Aids for the Hearing-Impaired

New technologies of speech-processing are rapidly being developed and applied for special communication needs. For example there are word recognizing systems that are used for sorting mail and for reporting defects during product-inspection. These and similar developments have a great potential for application to improve speech communication for hearing-handicapped persons.

The new speech-processing technology can also be applied to designing more-advanced hearing aids that enhance those speech patterns which are distorted or obscured by partial deafness. The technology is also applicable in tactile speech receivers and in prosthetic aids that produce sound through electrical stimulation of the auditory nerve.

The field of applicable technology for speech communication by the deaf has four main aspects: 1) signal enhancement in hearing aids, 2) tactile speech aids, 3) speech training, and 4) electrical hearing. Our Center program includes work on each of these.

ELECTRO-AUDITORY PROSTHESIS FOR HEARING

For some profoundly deaf persons, sensations of sound can be produced electrically if the auditory nerve is sufficiently stimulated by small electric currents. Recently several research groups have worked on developing a prosthesis for hearing using electrical stimulation.

Stimulating electrodes are implanted surgically in the cochlea which contains the sound-to-nerve (electrical) transducing organ of the ear. For many deaf persons it is only the transducer elements of the cochlea that are ineffective, while the auditory nerve-endings still remain responsive to direct stimulation.

When speech input activates a cochlear electrode, the deaf patient hears sounds. These sounds are described variously as fluctuating noises and buzzes that do not greatly resemble the input speech. Nevertheless, the patients, who are usually adults who formerly had normal hearing, report personal satisfaction with the sound they receive in their daily experience even though it is not very similar to what they experienced as normal hearing persons.

Current implant devices for clinical trails have the limitation of providing only one channel of speech information, but this is the most useful approach at present because the surgery and electrical processing are rather simple. The electrode is activated with the basic voice pitch component (fundamental frequency) of received speech or alternatively with the speech wave itself. Voice pitch alone is known to be a valuable aid to the deaf person in lipreading. The main unknown factor in these tests is the amount of benefit from the representation of voice-pitch that will be experienced by different implanted persons.

Evaluation of an Electro-Auditory Implant

Two otologists who have studied hearing through implants, Blair Simmons and William House, are beginning clinical trials of small groups at selected locations. The patients of our REC project will be implanted under Simmons' direction with cochlear stimulators designed by Robert L. White, of the Electrical Engineering Department at Stanford University. The electrode is inserted very superficially into the cochlea. The processor can be switched externally to stimulate in three different ways.

The current state of knowledge for encoding speech signals for stimulation of the auditory nerve is similar to that for tactile speech. Either approach provides only approximate impressions of the voice pitch and of the frequency distribution of the signal energy. Thus an important issue is the cost + risk/benefit ratio of electrical implant-hearing versus tactile "hearing". Knowledge of the expected long-term benefits, both psychological and communicative, would be of great importance to deaf individuals if they wish to choose between implants versus tactile stimulators. Certainly electrical hearing can provide immediate satisfaction, because the patient "hears again". Further, if the voice-pitch of speakers can be perceived electrically it is likely to improve lipreading. Similar help could be provided with tactile representation of the voice, even though perception would not occur through auditory channels. However, the tactile perception might, with extended experience seem like "hearing" since persons who have participated in long-term trials using tactile devices, and with lipreading, report that eventually the tactile information seems to come just as "directly into the head" as for hearing.

The objectives of our implant evaluations are to measure the long-term performance in speech perception of patients implanted with the single-electrode system and to compare their performance with that of similar patients who are fitted with tactile speech aids. Recently-deafened adult subjects are selected as possible subjects. All are totally deaf. The investigator for this project is William McFarland of the Gallaudet Audiology Department.

TACTILE AIDS FOR SPEECH RECEPTION

The sound patterns of speech can be presented as vibration patterns on the skin. The use of the skin as compared with lipreading or a visual aid would have advantages, especially in an aid for the deaf child, where it might be difficult or undesirable to restrict visual attention to the speaker.

A considerable amount of research has been carried out to test various types of tactile speech transmitters. Some of these are of the "spectral" type where the input acoustic waveform is analyzed into frequency bands and the outputs of the different bands are applied to different regions of skin. While it is now feasible to build arrays of tactile stimulators for a wearable spectral aid, development-oriented research is needed to improve the encoding of the speech parameters.

Our Center works on two different wearable tactile aids. One is of the "spectral type". This approach currently appears the most reasonable for a wearable aid that must function at a distance and provide information on the general environment as well as on speech signals. The amplitude in given spectral regions will be represented by amplitude of stimulation at the corresponding locations. The current work involves both engineering and psychophysical experimentation directed towards a final detailed design of the signal processing and vibrator transducer. Among the factors to be considered in this work are the number, center frequencies, and bandwidths of the various frequency channels; the contactors and speacing to be used in the array; and the characteristics of the signals used to drive the vibrators. Psychophysical experimentation consists of tests to guide the design choices. This project is carried out by Nathaniel Durlach of the MIT Research Laboratory of Electronics and his Sensory Communication Group.

A second, more-simple tactile aid will present three aspects of speech: the overall envelope information, whether a speech sound is voiced or unvoiced, and a representation of voice pitch. Tests will determine whether to represent voice-pitch spatially by having the same frequency of vibrations, but varying phase for two vibrators placed some distance apart, or by vibration frequency. It will probably be advantageous to divide the voice pitch frequency downward and categorize pitch into only a few classes that are salient to the skin. This project is carried out by Moise Goldstein and Charles Westgate of the Johns Hopkins University Department of Electrical Engineering.

A PHYSIOLOGICAL VOICE INDICATOR FOR THE DEAF

Deaf persons who are unable to hear their own voices often have great difficulty in learning to produce speech that is normally intelligible. A basic part of the problem is lack of feedback about voice production by the vocal cords. The cords must be closed and opened in proper coordination with the speech articulators, yet they cannot be seen and pointed to for instruction purposes.

The electroglottograph (EGG) is a device that may be used to monitor the states and functions of the vocal cords during speech. The EGG is a physiological pick-up and thus is not susceptible to environmental noise or to errors of measurement due to the concurrent presence of other features of the speech wave; such problems make acoustic monitors of the voice difficult to use or restricted in their usefulness.

The EGG receives signals from flat sensors placed on either side of the neck in the larynx area. The signal level is related to the degree and form of contact between the vocal cords. Thus, as the cords rapidly open and close, the signal fluctuations reflect their frequency and form of action in producing the voice.

The EGG has the potential to serve as a self monitor of voice pitch and as a training-indicator of the adjustment of the glottis for certain aspects of consonant production. Our Center work for an EGG aid consists of research on the signal processing algorithms necessary to derive new useful output or decisions from the EGG signals, and training aid development for voice pitch control by deaf speakers. The investigators are James Mahshie of the Gallaudet Audiology Department and Akira Hasegawa of the REC staff.

SPEECH-CUE ENHANCEMENT

It is now feasible to devise special speech-processing hearing aids to try to "correct" the auditory-patterns so they sound less distorted when presented to the individual hearing-impaired person.

The distortions of sound that are caused by hearing impairment probably involve both frequency information and time patterning. Microcomputer processing to alleviate these distortions has not yet been devised and tested. The potential here is very extensive in that the population to be benefitted numbers several million people in the U.S. alone, primarily those with moderate but serious impairment. However, the distortions experienced by these persons are not very well defined at this time. A detailed understanding of individual distortions would enable us to devise hearing aids with speech-processing technology to improve speech perception.

For example, for some impaired persons, the rapidly-changing frequency patterns which differentiate some of the consonants of speech are not distinguishable unless the changes are slowed somewhat or enhanced by exaggerating the shape of the frequency spectrum. For such a person special processing could be made available in the hearing aid that would detect rapid spectral changes in the signal, select and enhance an appropriate segment, and substitute the slowed enhanced segment for some portion of a following segment that is more steady in its spectrum.

Our speech-cue enhancement project examines an individual's hearing for effects of listening training and the enhancement of acoustic cues in facilitating speech perception. We determine whether discrimination of speech-sounds with natural, unaltered acoustic cues, can be facilitated through the use of identification and discrimination training tests that employ feedback. These tests are designed to discover enhancements of speech acoustic cues that were indistinguishable in their natural state.

A sequence of hearing tests is conducted using three categories of acoustic cues in speech sounds: duration cues, frequency-tempo cues, and onset/offset spectral cues. Each category of cues is studied in separate, successive experiments. The investigators of this project are Sally G. Revoile and J. M. Pickett of the REC staff.

SURVEY OF ASSISTIVE DEVICES FOR THE DEAF AND HEARING-IMPAIRED

One of the Center projects gathered an extensive file of information about assistive devices and visited centers of dissemination and device-development for the hearing impaired. A report is available which gives detailed descriptions and listings of this project's findings (Fellendorf, 1982). A summary of the report follows.

Assistive devices are broadly defined to range from simple visual "doorbells" to teletypewriters, to advanced concepts such as computer mail and automatic speech recognizers. Existing devices are described in the following classes: alerting and alarm systems, telephone assistive systems, personal listening systems, captioned TV, and large-room amplification systems. Descriptions are functional, in terms of the consumer-community and client needs, rather than in technical terms. In addition to existing devices, prototype new devices and trends in research and development are discussed; these include Picturephone®, computerized teletext services, speech synthesis, and speech recognition systems.

Device demonstration centers and other methods of dissemination are presented as models for meeting the consumers' needs to obtain and try out devices. Studies of consumer needs, preferences, and actions are summarized (nine studies are covered: 1974-1982).

Recommendations are made for future action to improve and develop further devices and to provide better education, cooperation of the concerned parties, and dissemination. An appendix lists nearly 200 currently available devices, their prices, and sources of supply.

We believe this report to be reasonably exhaustive of the field as of September 1982. It is intended primarily for professionals but will also be useful to consumers.

ACKNOWLEDGEMENTS

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REFERENCE

Fellendorf, G. A Survey of Current Developments in Assistive Devices for Hearing Impaired Persons in the United States. Gallaudet Research Institute, Gallaudet College, Washington, D.C. (Nov. 15, 1982).

Author Address: J. M. Pickett/SCRL/MTB/
Gallaudet College/Washington, D.C./20002.

SUBDERMAL STIMULATION FOR ELECTROCUTANEOUS COMMUNICATION

R. R. RISO, M. W. KEITH, K. R. GATES and A. R. IGNAGNI
Rehabilitation Engineering Center
Departments of Biomedical Engineering and Orthopaedics
Case Western Reserve University, Cleveland, Ohio, U.S.A.

ABSTRACT

We have demonstrated the feasibility of eliciting electrocutaneous sensations by means of fine coiled stainless steel wire electrodes, implanted so as to lie just under the skin. Such electrodes have been left in place for several months while protracted studies were performed. Preliminary results indicate that subdermal stimulation of the skin may provide a means by which sensory communication devices which are based on electrocutaneous stimulation may be designed so as to be implantable. The suitability of this mode of stimulation versus using silver concentric surface mounted electrodes was compared by evaluating the ability of subjects to make discriminations of pulse frequency over a range of 2-100 Hz. using both types of electrodes. Subjects reported that the sensations induced by the subdermal stimulation were more comfortable, more consistent and more distinct particularly at the higher frequencies than was the case with the surface stimulation. This resulted in an increase in the total number of JND's which could be distinguished over the range of frequencies tested.

INTRODUCTION

Electrocutaneous stimulation using surface electrodes has been employed by several investigators as a basis for artificial sensory substitution systems. These have included sensory feedback systems in arm prostheses [2,7,9], vocoders for the electrotactile perception of speech [8,11], and reading and mobility aids for the blind [3,4]. A recent review of electrocutaneous stimulation using surface electrodes is available in ref.[14].

Thus far, efforts to provide electrocutaneous devices to substitute for lost tactile sensation in the hand have mainly been directed toward users of myoelectric hands. There has been no work done that we are aware of to provide persons having sensory impaired natural hands with a tactile substitution system. These disabled persons derive from a large population which includes spinal cord injury, stroke, peripheral nerve lacerations and neuropathy. Lack of sensation severely limits these individuals ability to use their hands even when good motor function is preserved, or where the ability to grasp objects has been provided through artificial means such as Functional Electrical Stimulation [6]. In general, control of the impaired hand is obtained only through constant visual attention which can be burdensome. There is an enormous need to develop high quality sensory substitution devices to serve these people.

Patient acceptance of such devices will depend on system performance, reliability, ease of "donning", and cosmetic appearance. Sensory substitution systems which can be wholly implanted within the body will likely have the best chances for satisfying these criteria. As a part of the effort to achieve these goals we are developing techniques to elicit electrocutaneous sensations by means of implanted electrodes.

MATERIALS and METHODS

The electrodes which are initially being evaluated are made of tightly coiled fine stainless steel wire, similar to those developed by Caldwell and Reswick [1]. With the aid of a hypodermic needle, each electrode is inserted percutaneously and then the needle is withdrawn leaving the electrode to remain in place just below the surface of the skin. An adhesive backed, molded rubber cap is fixed to the skin at the site of entrance of the wires to provide protection and convenient electrical connection. With these techniques, the electrodes may be allowed to remain in place for many months. A cumulative total of 16 electrodes have been implanted in seven adult male subjects. The site of implantation for each of the subjects was limited to the skin overlying the lateral aspect of the upper arm (biceps C5 region). The electrodes are used monopolarly, connected cathodally and have an "active" deinsulated tip of 10 mm length. A large (5.0 cm x 5.0 cm) moistened cloth covered pad applied over the skin at the shoulder is used as a remote anodal electrode to provide a diffuse return pathway for the current.

RESULTS

With this electrode configuration, stimulation with single or bursts of monophasic, capacitively coupled pulses from a constant current source (pulse width 10-100 usec; freq. 2-100 Hz) has consistently elicited clear, distinctive sensations reported as having either a "tapping" or a vibratory quality which is localized to the electrode site.

Threshold Stability

Thresholds for electrocutaneous sensation using subdermal electrodes are typically found to require levels of current in the range of 0.3-5.0 ma., and this seems to depend upon each individual electrode after it has been installed. Figure 1 shows the relative stability of the threshold current as a function of time after implantation for three subdermal electrodes from the same subject. Each value represents the level of current that was required to produce threshold sensation at the start of the evaluation session on the day indicated (as measured using 50 usec pulses at 5 Hz).

The histogram of Figure 2 shows the distribution of the threshold currents for the 16 electrodes at approx. 7 days following implantation. The current range is 0.4 - 6.0 ma. with a mean of 1.4 ma. For 8 of these electrodes that were studied for at least 30 days, the mean current was 1.2 ma at day 7 and this value was unchanged at

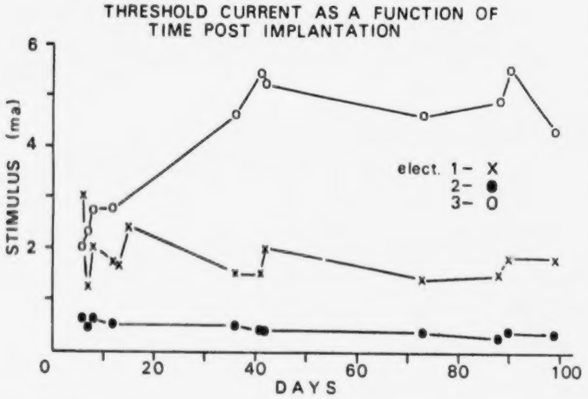

FIGURE 1

day 30. The data indicate that the electrodes retain their ability to stimulate the skin within reasonable limits of current. Mechanical stability of the electrodes within the tissues appears to be adequate. The dynamic range between the threshold for sensation and the level of stimulus current which causes discomfort has been measured on several occasions for the various electrodes and typically ranges between 3 and 5 times the threshold current. Interestingly, the dynamic range is found to expand as the subjects receive the stimulation day after day. This phenomenon has been studied by Solomonow and Prados [9] in studies in which surface electrodes were employed. He attributes the increase in dynamic response to a learning effect.

Just Noticeable Differences of Frequency

Successive JNDs of increases in frequency were determined over a range of 2-100 Hz for several subjects in order to determine the usable bandwidth and the theoretical resolution that would be available for a sensory feedback system in which grasp force was encoded by an electrocutaneous frequency modulation code. A psychophysical technique which has been described by Cornsweet [5] as the "Dual Staircase Method" was implemented in a computer assisted algorithm and used to obtain the data. This technique is an abreviation of the Method of Constant Stimuli in which a predetermined assortment of comparison stimuli are successively paired with the standard stimulus. The subject is required to indicate on each trial (stimulus pairing) if a change was perceived or not. The staircase method begins with pairings using comparison stimuli that are successively just slightly higher in frequency than the standard. An ascending series is continued until a level of comparison stimulus is reached which is sufficiently higher than the standard, so that the subject is able to detect the difference and gives a positive response. As soon as that event has occurred (or shortly thereafter) the direction of the staircase is reversed, and the next stimulus pairings that are given differ less and less from the standard until the subject responds that he can no longer discern any difference. At that point the descending series is terminated and another ascending series is begun. With this scheme repeated over and over the only stimulus pairings which are given (except at the very start of the procedure) are those in which the comparison stimulus is equal to or just brackets the JND value. This results in a highly efficient experimental technique. Trials in which the comparison stimulus is grossly beyond the JND or grossly short of it, seldom occur, and thus time is not wasted in documenting trial outcomes which the experimenter could have predicted.

At least 55 trials were given per test to determine the JND at each test frequency. As a control for haphazzard guessing a percentage of the trials were arranged so that no change occurred. Subjects controlled the time when the stimulus changed from the standard to the comparison on each trial by an electrical switch. A time delay of 750 msec was introduced between closing the switch and the actual substitution of the stimuli to ensure that this motor task did not interfere with the subject's performance of the frequency discrimination. The computer generated the frequencies, and when a shift was made it was executed instantaneously so that the very next interpulse interval was that which was appropriate for the comparison stimulus. Subjects were free to adjust the intensity of the stimulus at any time, and if they felt that any accommodation effects were becoming severe enough to compromise their judgements they could interrupt the testing and resume after a brief rest period during which the stimulus was turned off.

The subjects were well practised at the JND task before the data were recorded. As an example of the outcome, Figure 2 shows the results obtained from one of the subjects. The testing was also performed using a surface electrode (the electrode is described in ref. [4]) which was positioned directly over the location of the subdermal electrode. The data were collected by starting at 2 Hz and obtaining the JND (defined as 80% recognition) for the first level. This value was then taken as the new standard and the second JND was sought. The process was continued until the upper level of 100 Hz was reached. The two curves clearly show that the JND vs. frequency ratio is not a constant value but varies considerably with frequency. These findings confirm previous observations about the non-constancy of the JND vs. frequency ratio [13]. Our studies (and see [13]) indicate that the overall shape of the psychometric function obtained with any given subject is somewhat unique for each individual.

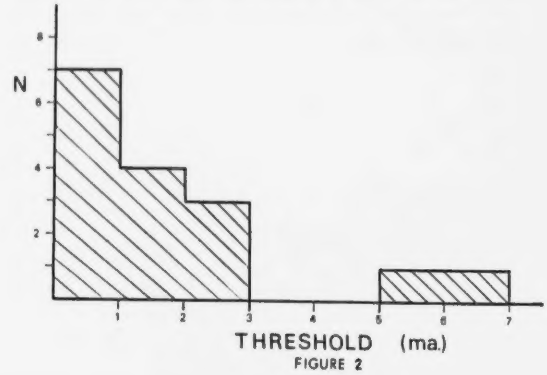

FIGURE 2

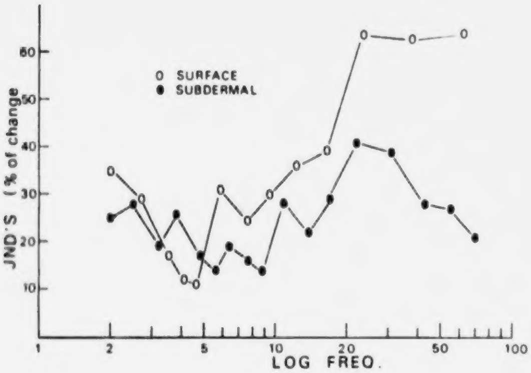

FIGURE 3

For the data shown in Figure 3 over the range of 2-55 Hz, an average frequency change of 24.3% for the JNDs was obtained when the skin was stimulated subdermally, whereas this was increased to 28.5% when a surface electrode was used. (The surface electrode is described in ref. [4].) For comparison, the surface electrode study performed by Szeto et al. [12] in which a Method of Adjustment was used to obtain the JNDs of frequency, yielded a comparable average value of 27.6% for a similiar range of frequency. The significance of our findings is that subdermal stimulation allowed this subject to discriminate at least 15 JNDs of frequency in the range of 2 - 55 Hz, whereas only 11 JNDs could be discriminated when surface stimulation was employed. The superior performance of the subdermal stimulation as compared to surface stimulation has also been demonstrated in a study in which JNDs for increases in frequency were measured from six standard frequencies of 2,5,10,30 and 50 Hz. The JNDs from each of the standard frequencies were expressed as percent change and then their averages were compiled separately for each of three subjects. The subdermal electrodes produced averaged JNDs which were lower than those obtained using the surface electrodes by 25%, 10% and 23% respectively for the three subjects.

DISCUSSION

The results of these preliminary studies are encouraging for the development of artificial sensory communications systems which may be wholly implantable and which are based on electrocutaneous codes. Studies are currently in progress to determine optimal stimulus waveform parameters and coding schemes. Future work should include investigation of the effects of electrode sizes and geometries and the development of multielectrode displays that might afford increased rates of information transfer or higher fidelity.

REFERENCES

1. Caldwell, C.W. and J.B. Reswick: A percutaneous wire electrode for chronic research use. IEEE Trans. Biomed. Eng., 22:429-32, 1975.

2. Collins, C.C. and J. Madey: Tactile sensory replacement. Proc. San Diego Biomed. Symp., 13:15-26, 1974.

3. Collins, C.C.: Tactile television: mechanical and electrical image projection. IEEE Trans. Man-Machine Systems, MMS-11(2):85-91, 1970.

4. Collins, C.C., L.A. Scadden, and A.B. Alden: Mobility studies with a tactile imaging device. Proc. of the 4th Conf. on Systems and Devices for the Disabled, Seattle, Washington, 1977.

5. Cornsweet, T.N.: The staircase method in psychophysics. Amer. J. Psychol., 75:485-91, 1962.

6. Peckham, P.H., J.T. Mortimer,and E.B. Marsolais: Controlled prehension and release in the C5 quadriplegic elicited by functional electrical stimulation of the paralyzed forearm musculature. Ann. Biomed. Eng., 8:369-88, 1980.

7. Prior, R.E., P.A. Case, and J. Lyman: Hook opening feedback for the below elbow amputee. Proc. San Diego Biomed. Symp., 16:357-68, 1977.

8. Saunders, F.A., W.A. Hill, and C.A. Simpson: Speech perception via the tactile mode: progress report. In H. Levitt, J.M. Pickett, and R.A. Houde, eds. Sensory Aids for the Hearing Impaired, New York, IEEE Press, pp. 278-81, 1980.

9. Scott, R.N., R.H. Brittain, R.R. Caldwell, A.B. Cameron, and V.A. Dunfield: Sensory-feedback system compatible with myoelectric control. Med. and Biol. Eng. Comp., 18:65-69, 1980.

10. Solomonow, M., and D. Prados: Further evidence on learning in the tactile sense. Proc. 4th Ann. Conf., IEEE EMBS, pp. 339-42, 1982.

11. Sparks, D.W., P.K. Kuhl, A.E. Edmonds, and G.P. Gray: Investigating the MESA (multipoint electrotactile speech aid): the transmission of segmental features of speech. J. Acoust. Soc. Am., 66:246-57, 1978.

12. Szeto, A.Y.J. and J. Lyman: Comparison of codes for sensory feedback using electrocutaneous tracking. Ann. Biomed. Eng., 5(4):367-83, 1977.

13. Szeto, A.Y.J., J. Lyman, and R.E. Prior: Electrocutaneous pulse rate and pulse width psychometric functions for sensory communications. Human Factors, 21(2):241-49, 1979.

14. Szeto, A.Y.J., and F.A. Saunders: Electrocutaneous stimulation for sensory communication in rehabilitation engineering. IEEE Trans. Biomed. Eng., BME-29(4):300-08, 1982.

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Ronald R. Riso PhD
REC, c/o Dept. Orothopaedics
Cleveland Metro. Gen. Hosp.
3395 Scranton Road
Cleveland, Ohio, 44109

NEW GENERATION SPEECH DISCRIMINATION TEST:
TENNESSEE TONALITY TEST

Kazunari J.M. Koike, Beth Brown, Harriet Hobbs and Carl W. Asp (University of Tennessee, Department of Audiology and Speech Pathology, Rehabilitation Engineering Center, Knoxville, Tennessee 37996-0740)

INTRODUCTION

Egan (1948)(1) listed several criteria for the construction of speech test materials. These criteria are primarily grouped into three categories: (a) common monosyllabic words; (b) materials be of equal phonetic composition and representative of speech; and (c) the lists be equal in range and average level of difficulty. Since then, traditionally, a speech discrimination test consists of monosyllabic words that are phonetically balanced (2) or that differ in initial or final consonants but have the same rhyme, e.g., pat vs. cat, sheep vs. sheet (3,4). Most speech tests followed Egan's first criterion without serious question. However, some questions have been raised regarding the necessity of the second criterion (5). Tobias (1964)(6) even stated that there is "overwhelming clinical and experimental evidence that indicates phonetic balance to be an interesting but unnecessary component of one of our current audiometric tests." The present study attempts to replace this component by selecting the test materials that are frequency-selective. While traditional speech discrimination tests give one overall discrimination score, they do not provide information on errors that are frequency-selective. In diagnosis and therapy, it is very useful to have a speech discrimination test that can provide such frequency selective information on errors. Such information is particularly important in correction of errors. The third criterion is unquestionably necessary for the construction of any reliable and efficient set of equivalent test (6). The purpose of the present study primarily concerns this third criterion.

This study was a preliminary study to develop a speech discrimination test that has frequency selectivity in the test words. It was assumed that frequency selectivity in the test words can be achieved by dividing them into different categories based on the pitch of the words which is termed as "tonality", not to be confused with fundamental frequency. The concept of tonality of speech sounds has been studied by many investigators (7, 8, 9, 10, 11, 12). Tonality words have been used also in the evaluations before and after auditory training with various filters and hearing aid placement at the University of Tennessee Verbo-Tonal Aural Rehabilitation Program. They have been found useful in determining the effects of the auditory training and in selecting an optimal hearing aid for a hearing impaired individual. However, a tonality word test has not been used widely in routine speech audiometry and various aural rehabilitation due to the lack of test lists which are equivalent in degree of difficulty.

The null hypotheses were: there are no differences in the mean scores among the five different tonality word lists, a) for normal hearing and b) for hearing impaired adults.

MATERIALS AND METHODS

Subjects

Seven normal hearing adults with an age range from 23 to 32 years (average 26 years old) and seven hearing-impaired adults with an age range of 20 to 70 years (average age 56 years) were used as subjects in the study. The normal hearing subjects were selected randomly at the University of Tennessee. Pure tone air conduction thresholds were obtained bilaterally. Pure tone averages ranged from 0 dB to 5 dB (average 2 dB) for the test ear. The hearing-impaired subjects were selected from the clinical files at the University of Tennessee Hearing and Speech Center and had a sensorineural hearing loss with a pure tone average ranging from 23 dB to 75 dB (average 49 dB) for the test ear. Although all of the hearing-impaired subjects have worn a hearing aid, the experience with hearing aids was not a criterion for subject selection. All the normal hearing and hearing-impaired subjects had normal tympanograms for the test ear.

Stimulus: Tennessee Tonality Test (TTT)

Each test list consisted of 30 monosyllabic words that were equally divided into low, mid and high tonality categories (see Table 1). For example, the words in the low category were selected by finding a word that primarily consisted of low tonality vowels and low tonality consonants according to the tonality model (12). Within each list the words from the different tonality categories were randomly distributed. There was a total of five different lists. The tonality words in each list were recorded by a male radio speaker

TABLE 1. List of the Tennessee Tonality Test

TENNESSEE TONALITY TEST RANDOMIZED LIST #1

STIMULUS	RESPONSE			STIMULUS	RESPONSE		
	L	M	H		L	M	H
1. TAP		___		16. BONE	___		
2. NO	___			17. HAT		___	
3. SEAT			___	18. ROW	___		
4. MOVE	___			19. TRACK		___	
5. CHEAP			___	20. TEACH			___
6. SHE			___	21. SHEET			___
7. CAT		___		22. BLUE	___		
8. WOOD	___			23. HOT		___	
9. LOT		___		24. SEE			___
10. EACH			___	25. ADD		___	
11. FAT		___		26. NEW	___		
12. CEASE			___	27. ROOM	___		
13. BOW	___			28. HAVE		___	
14. ROCK		___		29. SEEK			___
15. NOW	___			30. SIX			___
Subtotal	___%	___%	___%		___%	___%	___%
TOTAL	___%						

with general English with a four-second interval between words and were then recorded on a tape. In the following sections, this test was referred to as Tennessee Tonality Test (TTT).

TTT procedures

The right ear or better ear was chosen for the TTT. A pre-recorded tape of the TTT was presented through the same earphones and at the MCL for each subject. The subject was asked to repeat each test word without a carrier phrase and the tester wrote down the response. A criterion measure for each subject was the percentage correct for the test words correctly repeated among the total of 30 test words in each list.

RESULTS

Test-retest reliability

Test-retest reliability was determined by repeating the same list to the same subject approximately a week after the initial presentation. Two normal hearing subjects and two hearing-impaired subjects repeated all five lists of the TTT. The differences between the first score and the second score for all five lists were within 4% for the two normal hearing subjects. For the hearing impaired, the difference for one subject (S10) was within 7% while for another subject (S11) it was as large as 30%. These results suggest that the TTT is reliable for evaluating normal hearing adults. However, some variability is expected in test scores for hearing-impaired adults.

Test scores

Tonality test scores in percentage (%) correct of seven normal hearing and seven hearing impaired subjects are shown in Table 2.

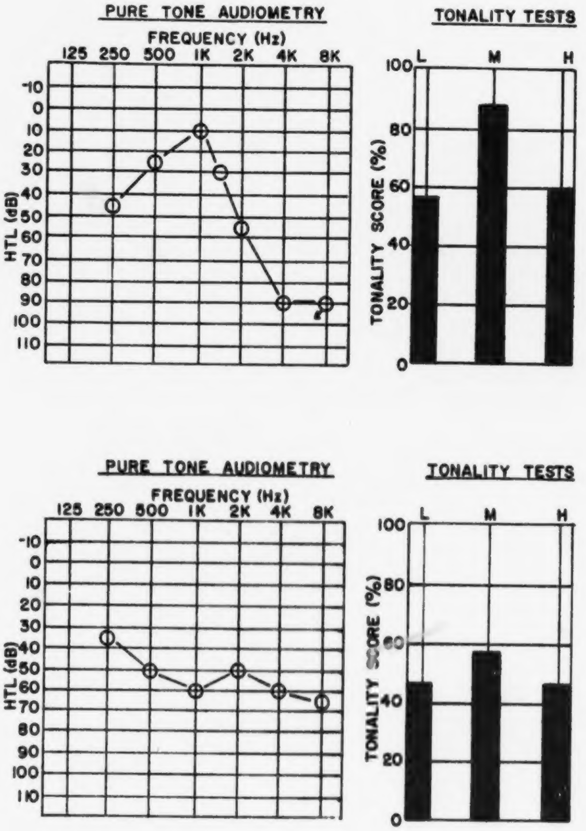
TABLE 2. Tonality test scores (%) for the normal hearing (1-7) and hearing impaired subjects (8-14).

		List				
Group	Subj.	1	2	3	4	5
	1	93	93	100	100	97
	2	100	100	97	100	90
	3	93	100	93	93	97
Normal hearing	4	97	97	93	93	93
	5	100	97	96	90	96
	6	97	100	100	97	97
	7	97	93	93	100	97
Mean		96.7	97.1	96.0	96.1	95.3
S.D.		2.87	3.13	3.16	4.14	2.75
	8	53	40	43	33	40
	9	43	70	43	43	57
	10	93	77	87	87	97
Hearing Impaired	11	80	63	87	73	83
	12	83	73	90	90	90
	13	80	57	80	73	80
	14	67	63	63	87	63
Mean		71.3	63.3	70.4	69.4	72.9
S.D.		17.86	12.31	20.75	22.70	20.24

The results were analyzed according to Treatments-by-Subjects (Repeated Measures) Design (13). There were no significant differences among the mean tonality scores of the five different lists for normal hearing and for hearing impaired subjects. It should be noted also that more variability in the tonality scores was observed among hearing-impaired subjects.

The configurations of the pure tone audiograms and the TTT scores for two hearing-impaired subjects are shown in Figure 1. Here the scores in three tonality categories were plotted separately according to each category.

FIGURE 1. The pure tone audiograms and the TTT scores of two hearing-impaired subjects.



DISCUSSION AND CONCLUSIONS

The advantage of using the TTT can be depicted in Figure 1, where the TTT scores (%) according to the categories are compared to the pure tone audiograms. The pattern of the TTT scores does not necessarily match the configuration of the pure tone audiograms; however, the pattern depicts which frequency area the hearing-impaired subject needs improvement in speech discrimination. This insight provides useful information in selective amplification and in correction of errors in perception and production.

The development of the TTT hopefully leads to a new generation of speech discrimination tests and creates some renewed interests in the field of rehabilitation. In this study, the TTT lists are found to be equivalent at one intensity level (the subject's MCL). However, the TTT still requires many series of studies for its development and the results of this preliminary study must be concluded carefully.

Suggestions for future studies

(a) List equivalency of the lists must be further examined at different intensity levels or at different signal-to-noise ratios. (b) The pitch model upon which the TTT is based must be carefully re-examined for further development of the TTT lists. (c) A correlation study is recommended to compare the degree of difficulty in the TTT words to that of the CID W-22 words. (d) The TTT should be administered to different groups of hearing-impaired subjects according to the degree and/or type of loss. (e) Frequency of occurrence in the English language for each word must be carefully examined and equalized, although all the test words in the present lists are found in Thorndike 20,000 common English words (14).

REFERENCES

1. Egan, J.P., Articulation testing methods. Laryngoscope, 58, 955-991 (1948).
2. Hirsh, I., Davis, H., Silverman, S.R., Reynolds, E.G., Eldert, E., and Benson, R.W., Development of materials for speech audiometry. Speech and Hearing Disorders, 17, 321-337 (1952).
3. Fairbanks, G., Test of phonetic differentiation: The rhyme test. J. Acoust. Soc. Amer., 30, 596-600 (1958).
4. Kreul, E.J., Nixon, J.C., Kryter, K.D., Bell, D.W., Land, J.S. and Shubert, E.D., A proposed clinical test of speech discrimination. Speech and Hearing Res., 11, 536-552 (1968).
5. Campbell, R.A., Discrimination test word diffibulty. Speech Hearing Res., 8, 13-22 (1965).
6. Tobias, J.V., On phonemic analysis of speech discrimination tests. J. Speech Hearing Res., 7, 102-104 (1964).
7. Boring, E., Sensation and Perception in the History of Experimental Psychology. New York: Appleton-Century Co. (1942).
8. Guberina, P., Verbo-Tonal method and its application to the rehabilitation of the deaf. In Report of the Proceedings of the International Congress on Education of the Deaf, Washington, D.C.: U.S. Government Printing Office (1964).
9. Peterson, M.M., A study of the perceived pitch of 23 prevocalic English consonants, Unpublished Master's Thesis, University of Tennessee, (1971)
10. Peterson, M.M and Asp, C.W., The perceived pitch of 23 prevocalic English consonants. J. Acoust. Soc. Amer., 52, Suppl. 1, S146, (1972).
11. Asp, C.W. and Berry, J., Test words grouped according to five pitch categories for selecting the frequency response for auditory training and hearing aid evaluation. Washington, D.C.: American Speech and Hearing Association Convention (1975).
12. Asp, C.W., Berry, J. and Bessel, C.S., The relative pitch of 30 English monosyllabic words: the rank order in comparison with a proposal model. J. Acoust. Soc. Amer., 64, Suppl. 1, S20, (1978).
13. Bruning, J.L., and Kintz, B.L., Computational Handbook of Statistics. Dallas: Scott, Foresman and Co. (1977).
14. Thorndike, E.L. A Teacher's Word Book of the Twenty Thousand Words Found Most Frequently and Widely In General Reading for Children and Young People. New York: Teachers Collection, Columbia University (1932).

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ADDRESS

Kazunari J.M. Koike, University of Tennessee,
Department of Audiology and Speech Pathology,
Rehabilitation/Center, Knoxville, Tennessee 37996-
0740.
Engineering

"An Assessment of Generalizability of 'Activity Potential' In Blind Rehabilitation"

Schulz, E.M., Wright, B.D., Lambert, R.W., and Becker, S.
RR&D Center
VA Hospital
Hines, Illinois

ABSTRACT

The scaling of ADL activities according to 'difficulty' was compared within and between groups of rehabilitation workers and blind persons. Person 'fit' statisitics showed that about 10 percent of the blind persons and 20 percent of the rehabilitation workers give the activities an atypical order of difficulty. Visual reading activities and unusual person traits contributed to the atypical ordering of difficulty. Discrepancies in the relative difficulty of activities revealed important differences between groups. These included the difference in patient sex ratios between rehabilitation institutions and the differences between pre- and postrehabilitation ability profiles in the visually impaired.

INTRODUCTION

Measures are needed in blind rehabilitation to coordinate diagnostic and training activities and to evaluate treatment outcomes. These measures must relate both to the blind person's experience and to the rehabilitation worker's frame of reference [2]. In our study of blind rehabilitation at USVA Hines Hospital, we are developing measures that will meet these requirements. The following analysis has contributed to our understanding of rehabilitation training, and illustrates a useful technique for developing generalizable measures.

BACKGROUND

In an earlier paper [4], we described a variable named 'activity potential' that was designed for blind rehabilitation. Seventy activities that pertain both to the instructional curricula of the rehabilitation program and to the day to day living experience of the blind were rated according to 'difficulty' by visually impaired persons. A latent trait measurement model, the Rasch model, was used to estimate activity calibrations and person measures on a logit, interval scale. 'Activity potential' is defined by the linear arrangement of activities on the interval scale.

The utility of a measure of 'activity potential' depends on how much information is carried by the measure. If 'activity potential' is generalizable, the measure, together with the arrangement of activities, shows which activities the patient will find easy to do and which he will find hard to do. It should be possible, then, for rehabilitation workers to use the person measures to determine which instructional curricula would be appropriate, which would be too easy, and which would be too difficult for the patient. Measures would not carry this kind of information, however, if the linear arrangement of activities were not generalizable from one person to another.

Person 'fit' statistics indicate whether the linear arrangement of activities applies equally well to all persons within a group. The expected difficulty of an activity for a person is a function of the difference between the person measure and the activity calibration. The linear arrangement of activities determines all of the predicted scores for an individual. A positive person fit statistic of 2.0 or greater means that too many activities were unexpectedly 'easy' or 'difficult' for that person. The activities would have to be rearranged, probably reordered, to accurately predict his scores. Thus the variable, 'activity potential' as defined by the linear arrangement of activities, does not generalize to that person.

Generalizability between groups is indicated by discrepancies between paired activity calibrations. The standardized discrepancy of an activity is the difference between its calibration by one group and its calibration by another group, divided by the standard error of the difference. Significant activity discrepancies between groups indicates specific ways the groups differ in their understanding of 'activity potential'. The discrepancies should be interpretable in terms of differences between groups or differences between the contexts of measurement.

In the present analysis we are attempting to learn about a measure of 'activity potential' by examining the interval scaling of activities 1) across both individual and groups of visually impaired persons, 2) across both individual and groups of rehabilitation workers, and 3) across rehabilitation workers expectations of untrained visually impaired patients and groups of trained visually impaired persons.

METHODS

The seventy activities defining 'activity potential' were scored for 'difficulty' by two groups of rehabilitation workers. One group (N=6) was from the Hines Blind Rehabilitation Center (BRC). The second group (N=8) was from the Illinois Visually Handicaped Institute (IVHI). The workers rated the activities on an eight category rating scale according to how difficult they expected the activities to be for blind patients entering their program. Four types of blind patients were considered separately: totally blind, low vision with predominant peripheral vision loss, low vision with predominant central vision loss, and visually impaired with multiple handicapps. The activities were rated separately for each type of blind patient producing a total of 56 sets of ratings.

The activities were also rated by two, randomly equivalent groups (N = 50 each) of visually impaired persons who had completed rehabilitation trainig at Hines at least six months previously. These persons rated the same 70 activities as the rehabilitation workers. Each group rated different lists of 50 activities having 30 activities in common. 'Difficulty' was rated on a 3, rather than an 8, category rating scale. The frequency of the four types of visually impaired patients approximately matched their representation by rehabilitation workers.

The computer program SCALE [3] was used to analyze the data separately from each of the above four groups. SCALE uses the rating scale form [5] of the Rasch measurement model [1] to estimate person measures and activity calibrations and to calculate expected scores and fit statistics using these estimates. Activity discrepancies were calculated using the activity calibrations and standard errors of calibration provided by the SCALE program.

RESULTS

Generalizability among visually impaired

Within groups, ten persons, out of 100, had significantly positive (p .05) fit statistics. Four were in group 1, and six were in group 2. Large positive fit statistics were associated with age less than 50 years, post-college education, and living in a city.

In comparisons between visually impaired groups, none of the 30 activities had significant discrepancies. The largest standard discrepancy was 1.59 for 'typing a letter'. The correlation between the 30 paired activity calibrations was .98.

Generalizability among rehabilitation workers.

Within groups, 14 out of 56 sets of ratings had significantly positive fit (p .05). Eight (out of 36) were in the IVHI group, and six (out of 24) were in the Hines BRC group.

Comparisons of Hines BRC workers' ratings with IVHI workers' ratings showed significant discrepancies for 12 of the 70 activities. Compared to the BRC workers, the IVHI workers said the following activities would be much easier for their entering patients:

- using the phone
- washing clothes
- identifying money
- playing a musical instrument
- using a tape recorder

The following activities were expected to be much harder by the IVHI group for their entering patients:

- fishing
- using power tools
- replacing a light bulb
- using a dog guide
- mowing a lawn
- replacing a fuse
- shoveling snow

The correlation between all paired activity calibrations was .93.

Generalizability between rehabilitation workers, prerehabilitation and blind, postrehabilitation.

Comparisons between rehabilitation workers and the visually impaired revealed significant discrepancies for 34 of the 70 activities. The activities significantly easier or harder for the trained visually impaired than anticipated by rehabilitation workers were:

Easier	Harder
cross intersection	brush teeth
cross street	play instrument
make meal	read label
use tools	use dog guide
dress up	read message
eat in public	play shuffleboard
do plumbing	weed garden
fix appliance	dust furniture
fix cord	play cards
type letter	play pool
use recorder	read bill
go to school	comb hair
use phone	read note
fix faucet	read article
write braille	play horseshoes
identify currency	unlock door
shave	make bed

The activities are listed in order of significance of discrepancy, from $t = 8.62$ for crossing an intersection to $t = 2.08$ for shaving, and $t = -5.96$ for brushing teeth to $t = -2.11$ for making a bed.

DISCUSSION

Person fit

Our findings on person fit indicate that the activities had a unique order of difficulty for about 10 percent of the visually impaired and 20 percent of the rehabilitation workers. These percentages are higher than would be expected by chance alone, and twice as high among rehabilitation workers as among the visually impaired. We identified three sources of large positive fit statistics among the visually impaired: 1) incomplete scoring procedures, 2) reading activities, and 3) special perso charactaristics.

Scoring procedures for 'difficulty' followed a multiply branching pattern in which the respondent was first asked if he ever performed a given activity. If he didn't, the activity was scored 'very difficult' or 'moderately difficult'. The category 'easy' would often have been more appropriate, but was never used. One person, for example, found most activities easy to do, but he did not own a tape recorder, and had false teeth. The activities 'using a tape recorder' and 'brushing your teeth' were then scored 'moderately difficult' rather than asking the person how difficult he thought the activities would be if he attempted them. The scores, 'moderate difficulty', for these activities made them seem much harder than many other activities - meaning a unique ordering of the activity difficulties, leading to large positive fit.

Several person with large positive fit gave unexpected responses to reading activities. Some of these person had special characteristics that may have been important in planning and evaluating their treatment. One man, under 30 years old, had multiple sclerosis, and found most activities very hard to do. He did have low vision, however, so he was able to read visually, with special aides and a Visualtech. Thus, the activities had a unique arrangement for him, with reading activities being easier than many of the other activities. Another man, with postcollege education, appeared to have a very negative attitude towards performing many activities. He did almost no home care, machine use or recreational activities, and he said that they were too hard for him to do. He further added at the end of his interview that he didn't think he could learn to do any of the activities better. However, he did have low vision and he did do reading and writing activities, using special aides and a Visualtech. So again, in this case, the linear arrangement of activities was different with reading activities being relatively easier than many other activities. These two cases show the diagnostic potential of fit statistics and point out the special nature of visual reading activities.

Activity discrepancies

We did not expect to find any differences in the relative difficulty of activities between groups of visually impaired respondents, since these groups were randomly equivalent. The lack of any activity discrepancies assures us that person measures mean the same thing in these groups.

Activity discrepancies between groups of rehabilitation workers points out differences between male and female patients. Almost all of the Hines BRC clients are male, but about half of the IVHI clients are female. The activity calibrations by IVHI workers then, should be more representative of female blind clients, and any discrepancies in comparison to calibrations by Hines BRC workers might reflect differences between male and female blind clients. Indeed, the activities expected to be harder by IVHI workers are traditional male activities - fishing, using tools, and home maintenance activities. The activities IVHI workers expected to be easier may be easier for women than for men - using the phone, washing clothes, etc.

Activity discrepancies between rehabilitation workers and visually impaired are attributable to the likely effects of rehabilitation training and to differences in considering reading activities. The activities that were relatively easier for the trained blind persons to do, i.e., crossing a busy intersection, crossing a street, making a meal, using tools, eating in public, making electrical and plumbing repairs, using a tape recorder, using braille and handling money are taught more thoroughly in the rehabilitation program than are the other activities in our list, which turned out to be relatively more 'difficult'. The 'more difficult' activities included specific games such as horseshoes, cards, shuffleboard and pool, which are taught only when persons express a preference for these activities. There may have been a ceiling effect for easy activities, like combing hair, brushing teeth, unlocking a door and making a bed. These activities become relatively more difficult because they did not become any easier, in contrast to most other activities, which did become easier through training. Reading activities appeared more difficult in scaling be rehabilitation workers because reading is not taught to most patients at Hines. Also, rehabilitation workers considered all forms of reading, including 'talking books', but visually impaired patients considered only visual reading. Nonvisual reading may be easier, on the average, than visual reading.

Consequences

At the present time, we are using an improved measuring instrument to study 'activity potential' in visually impaired patients both before and after blind rehabilitation. We are asking about skills that correspond to distinct instructional curricula in the rehabilitation program. Specifically, we are finding out how often the respondent does the skills without help, and how hard the skills are, or would be, to do without help. We are also asking how often the patients perform activities that the skills should enable the patients to do more frequently. Reading activities, by visual or nonvisual means, have been tentatively included. Recreational activities consist of general areas, i.e., 'outdoor sports', 'indoor sports', 'hobbies', etc. We expect most patients will show improvement in at least one specific activity within these areas. Data is being gathered on the amount of time spent by patients on specific curricula in the rehabilitation program. We expect to develop two or three 'activity' variables that correspond to specific patient ability profiles and instructional curricula, but are otherwise generalizable from one patient to another, and from prerehabilitation to postrehabilitation experience.

REFERENCES

(1) Rasch, G. Probabilistic Models for Some Intelligence and Attainment Tests. Copenhagen: Danmarks Paedogogiske Institut, 1969 (Chicago: University of Chicago Press, 1980)

(2) Rusalem, H. Coping With the Unseen Environment. Teachers College, Columbia University: Teachers College Press, 1972.

(3) SCALE, MESA Statistical Laboratory, 5835 South Kimbark, Chicago, Illinois, 60637.

(4) Schulz, E.M., Wright, B.D., Lambert, R.W., and Becker, S. A measure of activity capacity in blind rehabilitation. Proc Fifth Ann Conf Rehab Engin, 2: 112, 1982.

(5) Wright, B.D., & Masters, G.N., Rating Scale Analysis, MESA Press, Chicago, 1982.

12.1

THERAPEUTIC EQUIPMENT: FRIEND OF FOE?

Elaine Trefler, OTR M.Ed, Susan J. Taylor, OTR, Barbara Connally, RPT Ed.D

University of Tennessee Center for the Health Sciences
Rehabilitation Engineering Program
Memphis, Tennessee

INTRODUCTION

Pediatric therapists approach the challenge of treating children with brain damage from a common theoretical basis. The treatment goals are generally to inhibit the influence of abnormal pathological reflexes and in doing so help to normalize the tone. We work to facilitate movement into normal patterns of movement once the tone has been normalized. The interplay of facilitation with inhibition should lead to normal patterns of motion in the child.

A variety of therapeutic equipment is now available which can help to reinforce goals of treatment. We must keep in mind that no equipment can replace the treatment of qualified therapists, but it can serve as a valuable adjunct to a total treatment plan. Equipment can be used to realistically make a difference in the child's tone and function when children spend a considerable amount of school and home time in various pieces of adaptive equipment.

THE USE OF EQUIPMENT

It is important that therapeutic equipment be available to accomplish the same goals as are set in a therapy treatment session. For example, abnormal tone can be normalized by placing the child in reflex inhibiting postures, thereby shunting abnormal patterns of movement into functional postures. An attempt can also be made to decrease the influence of abnormally present reflexes by placing children in midline, symmetrical positions where the abnormal reflexes are prevented from dominating the child's basic posturing. Appropriately designed equipment can be instrumental in increasing the child's stability, particularly in the trunk and pelvis so that they can use their distal musculature for functional activities.

Appropriately designed equipment can be very useful in helping a child towards a more independent existence, especially once he/she reaches school age. For example, when equipment is appropriately prescribed, the child can become independently mobile. For a severely motor impaired individual who has been dependent on others for the first several years of their lives this is an incredible feat. Independent mobility can have numerous effects on the child's relationship to his/her environment. It often provides the child with their first opportunity to propel themselves through space. Mobility also encourages the child to assume increasing responsibility in daily life tasks. Socially, the child has opportunities to keep up with their peers, as well as to separate from their parents and other care givers which is fundamental for any child if they are to become independently functioning adults.

Another facet of independence in which well designed equipment is useful is in the area of activities of daily living which includes feeding, toileting, writing, etc. Severely motor impaired individuals can use a typewriter or computer for written output. They can interact in academic work through the use of computers. ADL equipment can make the toileting process less complicated or allow a severely motor impaired person to be independent in feeding skills.

There is a wide variety of therapeutic positioning equipment which is now available to give children access to their educational programs and environment. There are seating systems which give the children the functional use of their extremities through basic trunk and pelvic stability. Prone standers, wedges and side-lyers allow the children to be functional and work with normal patterns of motion. These pieces of equipment assist the brain damaged child in being well positioned when the pediatric therapist can not individually treat all the children within his/her school or clinic situations as regularly as might be ideal.

ABUSES OF EQUIPMENT

When equipment is poorly designed, prescribed, or monitored the advantages are nullified. A situation can be created where more damage than good is done. Cost factors increase and result in the wasting of already limited funds. Children who are left on pieces of equipment in one position for extended periods of time may loose mobility and may be spending more time in abnormal patterns of motion than in a more normalized position. Movement through space, even using less ideal patterns of motion, helps to prevent contractures and allows for somatosensory and perceptual input essential for normal development (1).

Some examples of equipment and what can go wrong over a period of time are as follows:

- A side-lyer is used with the severely motor impaired child to obtain a mid line oriented posture with a reduction in extensor tone. However, clinical observations show that often, the child's hips and neck go into extension, the shoulders into retraction and the trunk into rotation. Once the child has lost general midline posture that the side-lyer is no longer effective.

- In prone standers children are often positioned properly initially but then slowly move into an increased extension posture. In addition, lateral trunk flexion, hip flexion or hyperextension of the head may be seen. Once these postures occur, the prone stander is no longer considered an appropriate therapeutic positioner.

Finally, the child's independence can actually be decreased through the improper use of equipment. Their independent mobility (such as crawling) can be taken away by strapping them into pieces of equipment or seating systems for extended periods of time. In areas such as the home and classroom which cannot be directly under the supervision of a therapist, careful monitoring of equipment must be done so that the abuses are kept to a minimum.

EVALUATION AND MONITORING

The therapist has a large task in evaluating children for appropriate pieces of equipment and then monitoring their use. The proper programming and monitoring of this equipment is in tself a time consuming task. Not only must the therapist individualize the prescription, but he/she must also ensure that the equipment is being properly used for appropriate periods of time. This in itself is a monumental task. At present there are very few tools which are available to assist in this process. Only through scientific evaluation and monitoring of therapeutic equipment can it be determined whether, in fact, a piece of equipment is satisfactorily assisting with treatment goals and for what period of time each position is effective. It is anticipated that more accurate evaluation and monitoring will result in increased cost effectiveness. Therapists with little or no experience need to have the assistance of scientific tools to assist in treatment planning.

Evaluation Equipment

There is a great need for a variety of therapeutic evaluation tools to help determine which pieces of equipment are appropriate for which child and what their effect is on the child's posture and tone. Many of the therapeutic concepts that form the basis of treatment and equipment perscription that have been proposed over the years have very little scientific basis to substantiate their validity. Several examples of therapeutic concepts which have not been scientifically validated are as follows:

1. The occipital region of the head is theorectically a trigger point for increasing extensor tone. Seating Systems have been designed to avoid this region and clinically this has been observed to be true in most cases. However, there is need to scientifically validate whether this in fact is correct.
2. The ball of the foot is theorectically a trigger point for increased extension in the lower extremities through the neonatal positive supporting reaction. This has been observed in clinical settings, but there is no scientific research to document this phenomena.
3. Retraction of the scapula is used to obtain head extension and protraction to bring about neck flexion. This is a critical issue in terms of seating children with abnormal tone but there is scientific basis on which to guage decision making in the evaluation process.
4. The hip angle of 90° or less is used in seating to decrease extensor tone. Some studies have been done to validate this statement, but more precise parameters are needed in defining such things as the types of Cerebral Palsy being dealt with and how much hip flexion is needed to reduce extensor tone (2).

Improved evaluation tools derived from scientific investigation of the above claims could more clearly define, for example, positions which trigger abnormal pathological responses, or parts of the body needing positioning in order to help inhibit effects of abnormal primitive reflexes, thereby assisting in normalizing tone.

Evaluation

There are any number of evaluation kits and tools to use when one looks at the intelligence of an individual. There are, however, few tools available for evaluating equipment use. An example of available equipment includes the MPI simulator. The simulator is used to evaluate the moderately involved child with cerebral palsy for a seating system. It offers an almost infinite variety of positions in relation to hip angle, spatial orientation, etc. (3). Evaluation of the effects of positioning is dependent on the therapist's clinical observations as to whether or not muscle tone has indeed been normalized and whether the influence of abnormal pathology has been decreased. In the area of prosthetics, the myeloelectric testers to determine the availability of electrode sites in a scientific manner. The decision can then be made fairly confidently as to whether or not a child has the ability to operate a powered artificial hand or elbow. It would be most advantageous if similar evaluation tools were available in reference to therapeutic positioning equipment.

Monitors

Once the child is evaluated and it is determined which particular piece of equipment would be beneficial, there is still the challenge of monitoring what happens once the child is placed on or in the piece of equipment. Although the tone and abnormal primitive reflexes can be inhibited to an extent when the child is put on the piece of equipment there is no way of knowing for how long or in what manner the effects will be felt. A monitoring device would help considerably in determining how long a child can realistically be placed on a piece of equipment and have it work for the benefit of the child.

THE CHALLENGE TO ENGINEERS AND SCIENTISTS

A variety of scientific evaluation equipment be developed to assist the therapist in the prescription of therapeutic equipment. The Assistive Device Center at the University of California - Sacramento has developed a scientific procedure for evaluation (4). Simulators could evaluate reaction time, speed, and accuracy for the child being tested for powered mobility devices before a device is ordered. During seating evaluations of persons with insensitive tissue, flexible tissue pressure transducers could assist with decisions of contour and resilancy of seating surfaces. Corner chairs and prone standers which are multi-adjustable and whose components have feedback mechanisms could assist the therapist in determining what positions are most appropriate on an individual basis. Simulators and measuring chairs which could indicate tone changes would make the perscription of seating systems much more scientific.

A variety of monitoring equipment could be developed which would indicate when the child is properly positioned and also alert the therapist or teacher when it is no longer appropriate. For example, some mechanical contact switches could be incorporated into side lyers so that when the child's trunk begins to rotate and their upper shoulder retracts, a buzzer would sound. At this point the teacher could interject with specific facilitation to reposition the child as desired. Perhaps surface electrodes could be beneficial in seating systems to monitor head or neck position. These could alert therapists as to whether or not the system was doing what they had proposed in terms of neck elongation and head control. Devices built into shoes could alert the therapist that a child on a prone board is pushing down on the ball of the foot indicating an increase in extensor tone. She/he could then reposition the child, or position the child on an alternate piece of equipment. Infrared monitors could be developed that would alert the therapist when the child was no longer in a central position on a prone stander and she/he could facilitate a more normal midline position.

CONCLUSIONS

Therapeutic equipment, when properly evaluated and used, can be a dynamic adjunct to the multi-disciplinary therapy program of brain damaged children through the reduction of abnormal postures and tone, allowing the child to become more functional. However, the length of time and manner in which equipment is used must be carefully monitored. It must be ensured that the goals coincide with what can realistically be accomplished. There is a need for more interest in the area of scientifically evaluating and monitoring the use of equipment with children over time.

This is a time in our society when funding is being cut back for professionals in educational and clinical settings. Therapeutic equipment will be an even more important adjunct in the future. Parents are becoming increasingly involved in the treatment programs and are looking for ways of reinforcing goals of treatment in the home setting. Therapists must feel more secure that what they are proposing in terms of positioning in the classroom and in the home are indeed reinforcing their therapeutic goals.

The intent of this paper has been to inform rehabilitation professionals about the need and potential that exists for technical innovation, with particular reference to the brain damaged child. The combined talents of clinically qualified therapists working with the engineer and scientist has lead to significant achievements. Through more clearly defining the clinical problems and technical needs, hopefully these activities can be accelerated to meet the new challenges that we now face.

REFERENCES

1. Dennis, Wayne, Children of the Creche, Appleton-Century-Crofts Meridith Corporation.
2. Nwaobi, O.M., Electromyographic Investigation of Extension Tone in Cerebral Palsied Children in Different Sitting Positions, Dissertation - University of Virginia. Candidacy for the degree of Doctor of Philosophy, August, 1981.
3. University of Tennessee Center for the Health Sciences - Rehabilitation Engineering Center, Report of Activities, September, 1974 - June, 1976.
4. Coleman, C., Cook, A.M., Meyers, L., Final Report - Field Initiated Research Project - Enhancing the Educational Potential of Non-Oral Children Through Matching Communication Device Capabilities, Submitted, 1982.

Elaine Trefler
University of Tennessee - REC
682 Court Avenue
Memphis, Tennessee 38163

BIOFEEDBACK AND BEHAVIOURAL TECHNIQUES APPLIED TO REMEDIATION OF DROOLING: AN UPDATE

R. Koheil, A. Sochaniwskyj, K. Bablich, D. Kenny *, M. Milner +
Rehabilitation Engineering Dept., Ontario Crippled Children's Centre
* Hospital for Sick Children
+ and Institute of Biomedical Engineering, University of Toronto

INTRODUCTION

Drooling, defined as the presence of saliva outside the mouth, affects approximately 10 percent of the cerebral palsy population; stroke patients and head injured persons are also affected. Although not life threatening, drooling can be a serious handicap which may produce deleterious psycho-social, educational and physical consequences. For example: working surfaces and materials may rapidly deteriorate if they are constantly wet; educational staff may shy away from the child who is wet and surrounded by the odour of old saliva; physical discomforts may be experienced from the constant wetness which can also lead to tissue excoriation; the older child may feel socially unacceptable and withdraw from full participation in activities (5,7).

Treatment approaches to date have varied from conservative feeding programmes to more radical treatments such as surgery and radiation. A thorough review of pertinent literature has previously been reported (2,5).

A concerted effort has been mounted at the Ontario Crippled Children's Centre to address the problem of drooling.

Biofeedback training and behavioural modification techniques, engineering equipment design and computerized data collection and analysis are some of the avenues pursued by the research team which includes both therapists and engineers. The ultimate goal of this group is the development and refinement of non-invasive drooling treatment techniques.

It became apparent from a literature review (2,7) that there was no consistent and effective method of quantifying drooled saliva. This inadequacy made it difficult to objectively assess the efficacy of applied treatments - thus weakening the value of any conclusions drawn regarding a particular technique. Thus, the first problem that needed to be addressed was the development of an objective drool quantification technique.

A consensus was reached in the literature (3,1) and pilot work that drooling in cases of cerebral palsy is primarily due to oral-motor dysfunctioning and not hypersalivation. That is, these children either do not swallow properly, or do not swallow at a functionally adequate rate to keep the oral cavity clear of saliva. Other contributing factors to drooling are the child's emotional state; head position; sitting posture; concentration; malocclusion; tongue size and control; ability to form a tight anterior oral seal; decreased oral sensory awareness; and ability to nose breathe.

Cognizance was taken of all these factors and it was decided to investigate the importance of swallowing in the alleviation of drooling. Therefore, the second problem was related to studying the frequency of swallowing and oral motor functioning. The third problem was the designing of a clinical study aimed at increasing the client's awareness of the importance of swallowing and improving the efficacy of the oral musculature.

Problem #1: Drooling Quantification

In response to the first problem, the quantification of drooled saliva, an effective non-invasive drool quantification system (DQS) has been developed. This device has been described in detail elsewhere (6) and provides measures of drooled saliva to within 0.5 ml.

Problem #2: Monitoring of Swallowing Frequency

To address the second problem, that is, monitoring of swallowing frequency and oral muscle functioning it was decided to utilize surface electromyographic (EMG) recordings from three muscle groups. Information sought was in relation to the phasing, duration and amplitude of EMG activity. Masseter, orbicularis oris and the infra-hyoid group of muscles were chosen due to their anatomical and physiological relevance to the oralpharyngeal stage of swallowing, and their accessibility by surface EMG electrodes. Since these muscles have a distinct function and temporal sequence in a swallow it was anticipated that the effects of cerebral palsy on these muscles could be examined. A study was devised that examined the EMG patterns of 3 groups of 12 children; a normal group (Group 1); a group of cerebral palsy children who drool (Group 2); and a group of cerebral palsy children who do not drool (Group 3). Both unconscious and conscious swallows were investigated. Unconscious swallows are examined in a 1/2 hour quiet activity period (watching T.V.) and conscious swallows were examined while the subject performed specific drinking tasks.

To date the experimental work with Group 1 has been completed but not all the data analysis is finished. Groups 2 and 3 are receiving Ss on an ongoing basis. The data from the drinking tasks is being used to formulate definitive EMG patterns for a swallow for each individual subject. These patterns are being used to identify and count peaks of activity over the 1/2 hour of quiet activity so that a swallowing rate may be determined from the 1/2 hour quiet activity (that is, the frequency of swallowing while concentrating on another activity).

Figure 1 shows a typical integrated (IEMG) pattern from a continuous drinking exercise (75 ml.) for a normal child. There appears to be a large diversity of EMG patterns between normal individuals, but with consistent patterns being maintained between sessions.

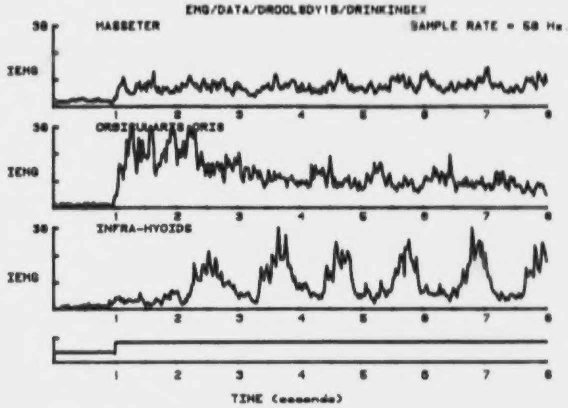


Figure 1: Typical EMG pattern for 7 seconds of continued drinking for a normal child.

However, cerebral palsy children who drool, do not appear to have a typical pattern even from swallow to swallow within subjects. Also there is an increased latency in the initiation of a swallow. These children have difficulty in moving liquid to the back of the mouth and as a result are unable to swallow as often in a limited time span as "normal" children. The EMG recordings also indicate deficits in lip closure ability (Figure 2).

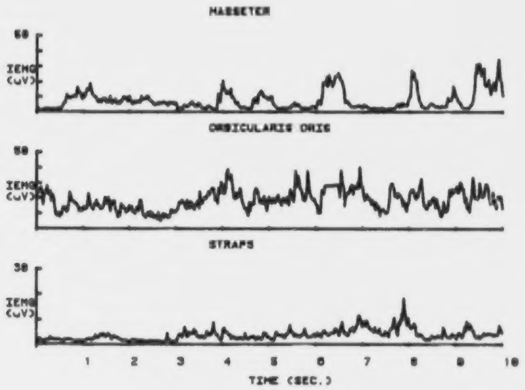
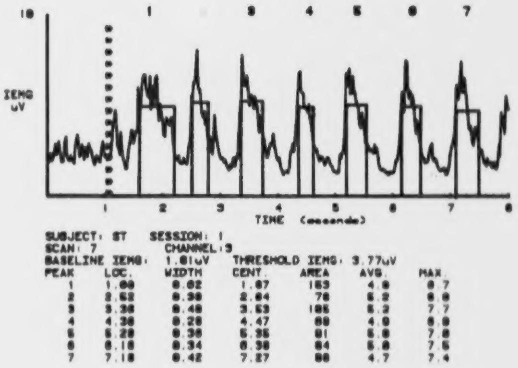


Figure 2: Example of an EMG pattern for 7 seconds of continuous drinking for a child with cerebral palsy who drools.

Figure 3 presents a sample of an analysis of EMG for one muscle and one drinking task. Information such as cycling, activation time and amplitude of EMG activity is assessed.

Problem #3: Clinical Training Study

A second study, clinically oriented, was designed to improve oral motor functioning and increase the awareness of the importance of swallowing. The study design is shown in Figure 4 and employs both biofeedback and behavioural techniques.



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SUBJECT: ST   SESSION: 1
SCAN: 7         CHANNEL: 3
BASELINE IEMG:  1.81uV   THRESHOLD IEMG: 3.77uV
PEAK    LOC.    WIDTH    CENT.    AREA    AVG.    MAX.
   1    1.00    0.02     1.87     153     4.8     8.7
   2    2.52    0.30     2.64      78     5.2     8.8
   3    3.36    0.40     3.53     185     5.2     7.7
   4    4.30    0.20     4.47      80     4.9     8.8
   5    5.20    0.30     5.35      81     5.8     7.8
   6    6.16    0.34     6.30      84     5.8     7.5
   7    7.10    0.42     7.27      88     4.7     7.4
```

Figure 3: Analysis of EMG for one muscle and one drinking task.

PHASE	EXPERIMENTAL CONDITION
A1	5 One-hour sessions (i) Drooling quantification (ii) Recording of 'unconscious' swallowing
B1	EMG Biofeedback training and swallowing at an auditory cue
A2	Baseline assessment
C1	'S' uses interval timer
A3	Baseline assessment
C2	Gradual withdrawal of timer
A4	Baseline assessment
D	One month period without timer
A5	Baseline assessment (follow-up)

Figure 4: Protocol for design of clinical study.

The DQS is used to give baseline measures of drooled saliva and commercially available EMG feedback equipment is utilized for the muscle training. To assist with maintenance of the newly acquired oral motor skills and to attempt to increase the swallowing frequency an interval timer (Accularm) was developed. This Accularm provides a repeating timed auditory signal to cue the S to swallow. The controlled timing interval can be varied from 1 to 99 seconds and received either overtly or covertly via earphones. The signal is usually presented at 30-40 second intervals. The concept of cuing swallows follows from the work of Rapp with retarded children (4). Generalization of the newly acquired skills to various environments is facilitated by the compact nature of the Accularm.

To date, 8 Ss have completed the study and 4 Ss are ongoing. Of the 8 Ss completing the study 6 have become significantly drier. The 2 Ss who were unsuccessful have been recommended for surgical intervention. Figure 5 shows typical data of a successful client during this programme. It appears that biofeedback of oral muscular functioning is an important tool for the remediation of drooling.

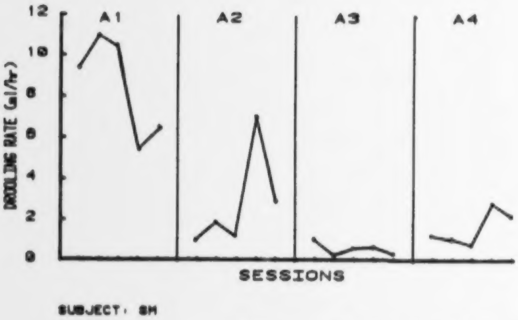

Figure 5: Drooling rate data for S in the clinical study.

Generalizing the Experience

As a result of the drooling research programme a Multidisciplinary Drooling Assessment Clinic has been established at the Ontario Crippled Children's Centre. This clinic services both out-patients and in-patients. A comprehensive oral-motor assessment is available and appropriate treatment recommendations are made such as: no treatment; feeding therapy; biofeedback training; surgery; dental work. For out-patients with a high level of oral-motor functioning, or ability to swallow on command, but who drool, a home behavioural programme utilizing the Accularm is available. Seminars describing the clinic, biofeedback and behavioural training techniques have been given to staff from other training centres and care-giving centres.

Discussion

Neurological deficits are almost always complex. Cerebral palsy presents a highly complicated spectrum of problems and the problem of drooling as exhibitited by cerebral palsy Ss is no exception. To address this problem a multidisciplinary effort has been required. Engineers designed and built the DQS and Accularms, and carry out EMG swallow pattern recognition and data analysis. Speech therapists conduct an oral motor assessment and physical therapists implement the clinical training aspects. This research, although still ongoing, has reached beyond the laboratory and has become service delivery oriented through the establishment of an assessment clinic. Newly designed equipment and techniques are being carefully evaluated over many Ss. Important information is being gathered in relation to swallowing patterns and rates in both normal and neurologically involved children. Clinically, biofeedback and behavioural cuing, although not panaceas, appear to have great potential in the conservative remediation of drooling.

ACKNOWLEDGEMENT

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REFERENCES

1. Ekedahl, C., Mansson, I., & Sandberg, N. Swallow dysfunction in the brain-damaged with drooling. Acta Otolaryngolgica. 78, 141-149, 1974.

2. Koheil, R. Progress report #1, Drool research project. Internal report, Rehabilitation Engineering Department, Ontario Crippled Children's Centre, 1980.

3. Makhani, J.S. Dribbling of saliva in children with cerebral palsy and its management. Indian Journal of Paediatrics, 41(319), 272-277, 1974.

4. Rapp, D.L., & Bowers, P.N. Meldreth dribble-control project. Child Care Health and Development, 5, 143-149, 1979.

5. Shein, G.F., Koheil, R.M., Mandel, A.R., Milner, M., & Sochaniwskyj, A. Behavioural engineering approaches to the problem of drooling. Proceedings of the Fourth Annual Conference on Rehabilitation Engineering, Washington, 301-303, 1981.

6. Sochaniwskyj, A.E. Drooling Quantification: noninvasive technique. Archives of Physical Medicine and Rehabilitation, 63, 605-607, 1982.

7. Sochaniwskyj, A.E., & Shein, G.F. Drooling assessment of children with cerebral palsy. 9th Canadian Medical and Biological Engineering Conference Digest of Papers, Fredericton, N.B., 65-66, 1982.

Ontario Crippled Children's Centre
350 Rumsey Road,
Toronto, Ontario,
M4G 1R8

12.3

SHOULDER EXERCISE INCENTIVE SYSTEM

Ronald F. Gaines, MD, David Dungan, Gordon Hosoda, BS, LuAnn Piccard, BSME,
Peter W. Axelson, MSME, Melva S. E. Chang, BSEE.

Spinal Cord Injury Center & Rehabilitation Research and Development Center
Palo Alto Veterans Administration Medical Center

ABSTRACT

A shoulder driven control for commercially available video games is described. It is designed to provide an incentive for therapeutic exercise of shoulder girdle muscles during rehabilitation in quadriplegia. Clinical experience with the system is discussed from the perspective of teaching a person to use the remaining voluntary shoulder muscles for balance and trunk positioning as well as arm placement.

INTRODUCTION

During the early phases of physical rehabilitation, a quadriplegic patient must learn to use limited remaining voluntary muscular resources to perform as many skills as possible. Shoulder girdle muscles, which can exert forces in a wide range of directions, are necessary for trunk balance as well as arm positioning in quadriplegia. Trunk movement ability is of special importance because it is the only independent voluntary mechanism for adjusting seating pressures in this group of patients. Nevertheless, the focus of shoulder exercise during rehabilitation is improving the arm positioning function.

At our center, exercise of the shoulder girdle muscles is incorporated into mat activities and whole arm conditioning exercise for the achievement of self care skills. Since no specific exercise is directed at the balance and trunk positioning function of the shoulder girdle muscles, we have developed a shoulder driven video game controller to serve as an incentive for recently injured quadriplegic patients to work on this during rehabilitation.

BACKGROUND

Maintaining interest in therapeutic exercise is an essential role for therapists, whose very presence provides an incentive to work. For infants and children, play is central to most therapeutic exercise routines. Although older patients can make exercise an end in itself, it is easier if it is fun. Exercise incentives provided by electronically mediated tasks with video displays have been used to encourage stroke and head injury patients(1-3), in whom visual-motor integrative function itself may be impaired(4). In this study we introduced a modified game controller which specifically requires use of the shoulder girdle muscles for game play. In this report, we describe clinical experience with the exercise system which consists of a shoulder harness to which the controller attaches and the video game.

MATERIALS AND METHODS

The first step was to design and build a rough prototype to see whether the trunk positioning exercise characterized by protraction, retraction and elevation of the scapula was suitable for driving a video game, and whether these movements in quadriplegics would result in noticeable shifts of body position. Next, an advanced prototype controller was designed and built. The specific design objectives included quick set-up, a stable connection between the top of a user's shoulder and the control itself, and reproducibility with inexpensive parts. We wished to have a reasonably flexible design so that the control could be used to exercise other joint movements later.

Figure 1. Quadriplegic using the system.

The mechanical design of the controller circuit permits independent registration of movements with 2 degrees of freedom, up and down and forward and backward. The movements drive slide potentiometers whose positions may be read by the electronics. Adjustable comparitor circuits permit changing the distance a user must move before the movement results in the simulation of the Atari(TM) joystick. An adapted reset switch permits independent use by a quadriplegic after initial set-up. The second prototype system is pictured in use in figure 1.

With the completion of the second prototype, a clinical trial was initiated. Six patients used the games while numbers of repetitions of the necessary movements were counted; game scores and time playing were also recorded.

A third mechanical prototype has also been completed which gives a smoother functioning system for further investigation. It is designed for use with a monitoring system in parallel with the video game so that objective data on the movement itself may be recorded automatically.

RESULTS

Observations of the initial experience with the first prototype demonstrated improvement of skills with each bout of exercise. In addition, users endurance with the system increased. Average game scores at each consecutive session for the two patients who used the initial prototype most are illustrated in figure 2. These users, and the others, reported appreciation of the skills we were trying to encourage. The need for easy set-up was recognized, and addressed in further development.

In the second clinical trial, we observed a nearly log-linear relationship between the Space Invaders(TM) game scores and the numbers of repetitions of forward/backward movements. We observed that the up and down movements did not match so well since some players constantly kept the control in the up position which corresponds to the firing button on the Atari(TM) control.

Several able-bodied volunteers played the shoulder control game while sitting in a wheelchair barograph(5). This device records relative seating pressures with a visual display. The barograph seating surface is not cushioned and is used for asensory patients only for teaching purposes. As expected, playing the game resulted in observable shifts of weight.

DISCUSSION

This study illustrates the role of directed exercise incentives during therapeutic exercise. We chose the shoulder movement because of the difficulty our therapists encounter in teaching the important shoulder girdle controlled body movement functions to recently injured quadriplegics; other joints which may be used without major changes in the mechanical system include wrist, fingers and hip. Other adaptations would be necessary to make the system work for exercise of any other joints. The success we had with the shoulder game was sufficient to introduce the system into our regular rehabilitation therapy.

The use of off-the-shelf video games for incentive, as compared with the standard video tasks described by others, provides a degree of familiarity to the patient. However, the mechanical design for this system is not as integrally related to the electronically mediated task as might be in the other systems. The separation of game objective from exercise objective is seen as a factor in increased incentive.

The recreational incentive to a poorly defined exercise is paramount, and served as the stimulus for this project. As expected, the observed response of the rehabilitation patients emphasizes the potential for use of a system such as ours for a other exercises for able-bodied as well as disabled persons.

Our further work includes refinement of the control and attachment of a monitoring system. These will be described in the presentation.

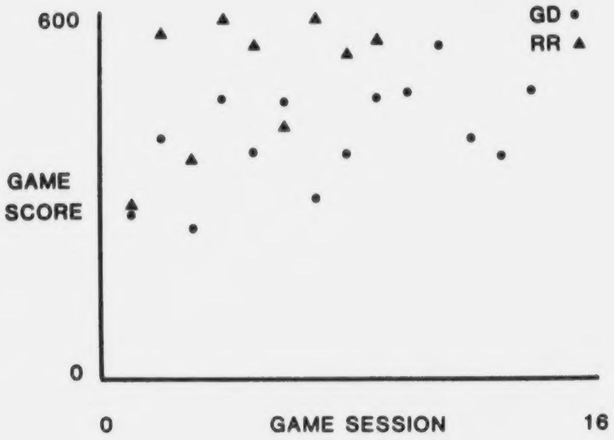

Figure 2. Two users' scores using the first prototype system.

REFERENCES

1. Lynn PA, Reed GAL, Hewer RL, Parker WR. Some applications of human operator research to the assessment of disability in stroke. Medical and Biological Computing and Engineering 15:184-188, 1977.

2. Meadows PM, Bowman BR, Sperry CD. A microprocessor based upper extremity placement trainer. Proceedings of the Fourth Annual Conference on Rehabilitation Engineering, 292-294, 1981.

3. Meadows P, Parker K. Evaluation of the Rancho tracking treatment for treatment of the hemiparetic wrist. Proceedings of the Fifth Annual Conference on Rehabilitation Engineering, 51, 1982.

4. Lynn PA, Parker WR, Reed GAL, Baldwin JF, Pilsworth BW. New approaches to modelling the disabled human operator. Medical and Biological Computing and Engineering 17:344-348, 1979.

5. Vistnes LM. Pressure sores: Etiology and Prevention. Bulletin of Prosthetics Research 17:123-125, 1980.

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Rehabilitation Research and Development Center
Palo Alto Veterans Administration Medical Center
3801 Miranda Avenue
Palo Alto, California 94304

DEVELOPMENT OF VOCAL AND SPEECH TRAINING SYSTEM FOR THE HEARING IMPAIRED

T. Misu*, T. Isomura**, H. Funakubo**, K. Hayashi* and C. Kushler***
* Dept. of Prec. Mach. Eng., Chiba Institute of Technology
** Dept. of Prec. Mach. Eng., Fac. of Eng., Tokyo University
*** Dept. of Comp. Sci., Michigan State University

ABSTRACT

Many people whose speaking ability is impaired due to hearing deficiencies are able to improve their speech with proper training, and thus become better able to function in a modern active life. Most of such training is currently available only in a fixed place such as a hospital from a clinician, usually a speech therapist. Generally, this kind of training requires a highly trained instructor and persistent efforts over a long period of time.

Accordingly, we developed a speech training system which can be used independently or in cooperation with a family member at any time and at any place.

In this report, we shall describe the hardware and software of this system which extracts the parameters of vowel sounds, evaluates these parameters, and provides feed back to enable the trainee to correct their pronunciation.

INTRODUCTION

Communication by means of speaking is one of the most important things in human daily life. The various training methods for people with impaired hearing ability differ according to the nature and degree of their impediments, and in some ways are not systematized clearly in Japan. Moreover, the field of speech therapy has experienced many recent developments, despite a shortage of practicing speech therapists. Due to the rapid progress of electronic technology, there have been many advances in processing techniques for sound signals which have found applications in many fields. The utilization of modern micro-electronic technology should prove to be most effective in helping to remedy the present condition of the hearing impaired, as mentioned above.

The object of this study is to develop a portable, simple, and inexpensive speech training system which will enable a hearing impaired person to engage in effective speech training even in the absence of a trained speech therapist. A second goal is to establish a data-bank in order to systematize training methods which were until now strictly in the domain of the "know-how" of the speech therapist.

In this study, the main object is to correct the pronunciation of vowel sounds by the hearing impaired. With future research, this system may also possibly find application in the training of these with cerebral palsy.

Most systems which perform analysis and or recognition of speech utilize large or mid-size computers which are prohibitively expensive. An important facet of thus system is that only micro processors and signal processor chips are used in extracting and evaluating the parameters of the speech waveform. The system is thus able to perform a variety of analyses, yet the overall cost is kept reasonably low. The data-band system is designed to be able to interface with many kinds of commercially available personal computers. We describe the details of the system's design, its functions, the algorithm used for the extraction and evaluation of parameters, and the method of its use.

SUMMARY DESCRIPTION OF THE ENTIRE SYSTEM

A block diagram of the entire system is shown in Fig. 1. The system consists of the input voice signal pre-processor, the central control unit for the extraction of the speech parameters, evaluation, and instruction display unit for the results of the evaluation and for the content of instruction, a monitor, and operating console for choosing the training items and setting up the training conditions. The entire system is shown in Photo 1. The pre-processor converts the original sound wave to a digital representation. The original wave form is low-pass filtered (Cut off frequency 4.5KHz) and degitized to 8bits at a 10KHz sampling frequency. The central conrol unit consists of a Z80 as the main CPU (clock 2.5MHz), 8Kbyte of ROM, 16Kbyte of RAM, μPD7720 signal-processors (clock 3.5MHz) for use in the extraction of the parameters of vowel sounds, and PIO.

We use four signal-processors for obtaining the auto-corelation, linear predictive coefficients, resonance frequency, and pitch frequency. The main CPU inputs the sound data from the pre-processor, controls the signal-processors, and carries out the evaluation of the extracted results, instruction and display. The display control unit consists of Z80, ROM8Kbyte, RAM16Kbyte (including Video RAM14Kbyte) VDG, RF Modulator and PIO.

In this system, the original wave form, its fundamental pitch, formant frequencies, the corresponding standard vowel, evaluation results, instruction contents, etc., can be displayed by the commands of the central control unit. The operation of the system is controlled by means of switches which constitute the operating console.

TRAINING METHOD

The method of training is shown in Fig. 2. There are two basic types of training available. One is basic speech generation training, and the second is training for the pronunciation of a specific vowel. Basic speech generation training consists of (A) the volume of the sound produced (B) the duration of the speech output, and (C) pitch modulation. Each training item has several levels from low to high. In this type of training, the main parameter extracted is pitch. The training for a specific vowel consists of (A) independent speaking of the five Japanese vowels a, i, u, e, o. (B) combination with basic speech generation training, (C) combination vowels such as ao, ai, ue, etc. In this type of training, the main parameter extracted is the linear predictive coefficients of the wave form. In both basic speech generation training and in training for a specific vowel, the original wave, the evaluation results and the contents of instructions are displayed each time on a monitor. Training items are chosen, and the nature of the display desired is selected by means of the appropriate switches on the console. The treatments of a central control unit are shown in Fig. 3. The modes of functioning of the unit in Fig. 3 are shown in Table 1. Mode 4 is used when the user wants this system to combine with a personal computer (for the management of data, for example).

ALGORITHM FOR EXTRACTING PARAMETERS & METHOD OF EVALUATION AND INSTRUCTION

The process used to extract parameters and evaluate them is shown in Fig. 4. A speech waveform passes through the A/D converter (8bit, sampling frequency 10KHz) and sampling data$\{X(n)\}$ are obtained. Next, we weight these data in Hamming Window Function, calculate the auto-corelation function which is used to find the power spectra of the original waveform by the theory of Hinchi. The equations of the Hamming Window Functions (1) and the auto-corelation function (2) are shown as follows:

$$W_{(n)} = 0.54-0.46\cos\left(\frac{2\pi n}{N-1}\right)\quad (0\leq n\leq N-1) \tag{1}$$

(N: number of data points used (256),
n: sample number)

$$V_t = \frac{1}{N}\sum_{n=0}^{N-1-t} X_n \cdot X_{n+t} \tag{2}$$

Next, we obtain the linear predictive coefficients Ai as follows:

$$\begin{bmatrix} V_0 & V_1 & V_2 & \cdots & V_{p-1} \\ V_1 & V_2 & V_3 & \cdots & V_{p-2} \\ V_2 & V_3 & V_4 & \cdots & V_{p-3} \\ \vdots & & & & \\ V_{p-1} & V_{p-2} & V_{p-3} & \cdots & V_0 \end{bmatrix} \begin{bmatrix} A_1{}^{(p)} \\ A_2{}^{(p)} \\ A_3{}^{(p)} \\ \vdots \\ A_p{}^{(p)} \end{bmatrix} = - \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ \vdots \\ V_p \end{bmatrix} \tag{3}$$

We solve the equation (3) by means of the Durbin-Levinson-Itakura Method (shown in Fig. 5). The descriptions in the flowchart of Fig. 5 are based on the following relations:

$$K_n = W_{n-1}/U_{n-1} \tag{4}$$

$$U_n = U_{n-1}(1-K_n)^2 \tag{5}$$

$$A_i^{(n)} = A_i^{(n-1)} - K_n A_{n-i}^{(n-1)} \tag{6}$$

$$W_n = \sum_{i=0}^{n} A_i^{(n)} V_{n+1-i} \tag{7}$$

We determine the similarity to the target vowel according to standard values of these parameters. we evaluate the fundamental pitch frequency from the sampled data using the zero-crossing method, and make the V/NV decision. Fig. 6 shows an example of the evaluation of basic speech training. Fig. 7 shows an example of the evaluation and resulting instruction in training for a specific vowel. The comments on each of the vowels in Fig. 7 show the instruction which may be issued.

CONCLUSION

In this paper we have presented the design of a microprocessor based speech training system for basic speech training and for the pronunciation of specific vowels. We have established the basic technology (both hardware and software) used in this system. The next step is to further systematize the resulting instructions given to the trainee. This must be done by collecting and analyzing field-test data, and incorporating these results into an integrated system.

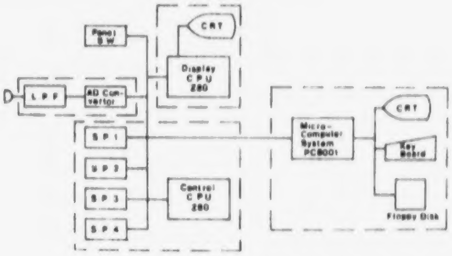
Panel SW
CRT
Display CPU Z80
LPF
AD Converter
SP1
SP2
SP3
SP4
Control CPU Z80
Micro-Computer System PC8001
CRT
Key Board
Floppy Disk

Fig 1 Block Diagram of Speech Training System

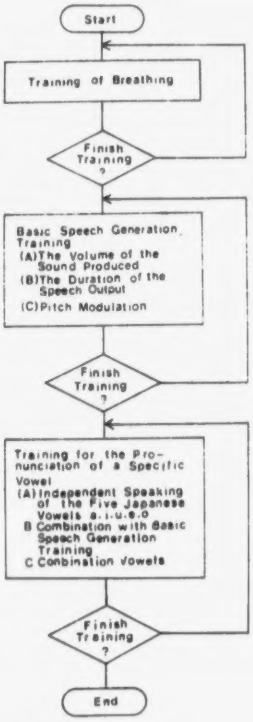
Start
Training of Breathing
Finish Training ?
Basic Speech Generation Training
(A)The Volume of the Sound Produced
(B)The Duration of the Speech Output
(C)Pitch Modulation
Finish Training ?
Training for the Pronunciation of a Specific Vowel
(A)Independent Speaking of the Five Japanese Vowels a.i.u.e.o
B Combination with Basic Speech Generation Training
C Conbination Vowels
Finish Training ?
End

Fig.2 Flowchart for Training

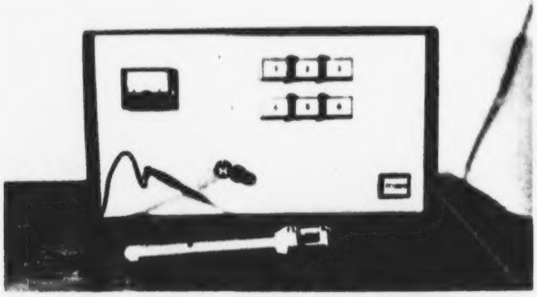

Photo. 1

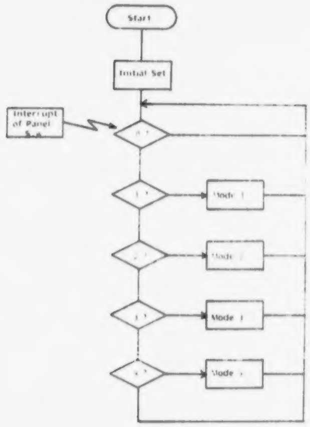
Start
Initial Set
Interrupt of Panel S-n
Mode 1
Mode 3

Fig.3 Flowchart of Main Control Unit

Table.1 Table of the System Mode

System Mode	Job
0	Wait the Command Input, Display the Explanation of this System
1	Sound Wave Form
2	Pitch Training Mode, Display the Pitch
3	Vowel Training Mode, Display the Position and Indicate Mouth Form
4	Change the Command Input from PC8001 and Do the same Job 0 to 4, and Control the Data

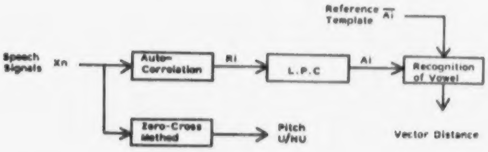
Reference Template $\overline{Ai}$
Speech Signals
Xn
Auto-Correlation
Ri
L.P.C
Ai
Recognition of Vowel
Zero-Cross Method
Pitch U/NU
Vector Distance

Fig.4 Block Diagram of Algorism for Recognition

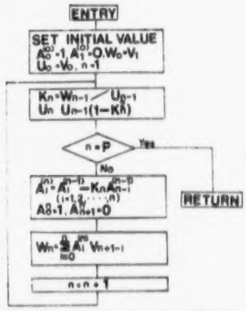
ENTRY
SET INITIAL VALUE
$A_0^{(0)}=1, A_1^{(0)}=0, W_0=V_1$
$U_0=V_0, n=1$
$K_n=W_{n-1}/U_{n-1}$
$U_n=U_{n-1}(1-K_n^2)$
n=P
Yes
No
$A_i^{(n)}=A_i^{(n-1)}-K_nA_{n-i}^{(n-1)}$
(i=1,2,···,n)
$A_0^{(n)}=1, A_{n+1}^{(n)}=0$
$W_n=\sum_{i=0}^{n} A_i^{(n)} V_{n+1-i}$
n=n+1
RETURN

Fig.5 Durbin-Levinson-Itakura Method

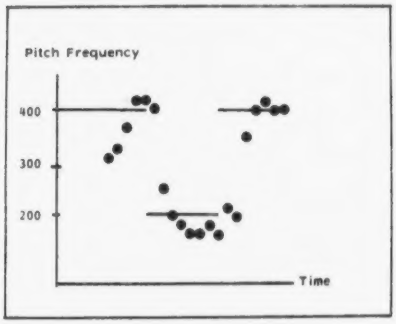

Fig.6 Display of Pitch Training

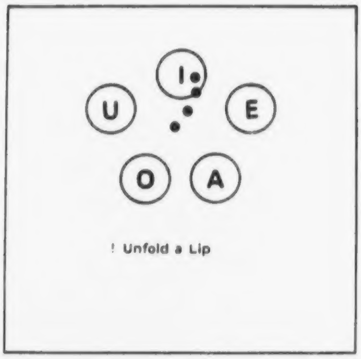
I
U
E
O
A
! Unfold a Lip

Fig.7 Display of Vowel Training

REFERRENCE

1. Nakata, K. and Sanpei, T.
The Applications of Voice Devices:OHM Co.1982

2. Saito, S. and Nakata, K.
The Basis of Digital Processing of Voice
Signals: OHM Co. 1982

FUNAKUBO Lab. Dept. of Prec. Mach. Eng. Fac. of
Eng. The University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo Japan (113)

12.5P

ACTION, INTERACTION, AND THE THRILL OF POWER: SOME DEVICES FOR CONGENITALLY DISABLED CHILDREN

Jim Tobias
Matheny School
Peapack, New Jersey 07977

INTRODUCTION

It is a commonplace that the greatest impact of congenital disability is the disruption of normal patterns of child development. Whether through institutional or parental over-protection and low expectation, or through the actual physical and cognitive limitations imposed by the disabling condition itself, the disabled child is at a marked disadvantage. In the child's attempt to achieve success, the delays and deficits noted by parents, teachers and clinicians are often taken as tragic but immutable consequences of a physical fact; this attitude further reinforces the syndrome of low expectation/low achievement.

The image of child development is one of travelling distances, overcoming obstacles, and crossing bridges. The word "milestone" is a convention to denote a developmental goal. The disabled child is obviously presented with higher "tolls" and lower "gas mileage" on this trip. What conventional therapies have excelled at doing is to map the route, carefully noting obstacles ahead, and to provide alternate roads and bridges past the same or similar milestones.

Rehabilitation engineering is best seen not as a separate discipline in this context, but as just another tool, another set of methods and materials to accomplish the same goals as traditional therapies. The only thing really new about rehabilitation engineering is its focus on technology as the source of solutions, which opens up a wide range of approaches to therapeutic problems.

In addressing the needs of congenitally disabled children, the notion of substituting an action the child can perform for one the child cannot or finds difficult to perform, a notion comfortable to therapists and special educators, is taken qualitatively further in rehabilitation engineering. Instead of teaching a child how to supplement his leg power in walking with crutches, the rehabilitation engineer replaces the leg power altogether with hand power at the joystick of an electric wheelchair. For good or ill, this substitution means a radical rethinking of the concept of mobility, for now the child's legs become irrelevant to getting around, and only the fine motions of completely different muscles count for anything. Similarly, the vocal speech function may be replaced by the activation of a communication aid by head pointer. These changes demand higher cognitive functioning in a way, for they demand that the child think in order to substitute "irrelevant" muscles for the non-functioning ones.

The payoff of this greater cognitive demand should be increased personal control, the thrill of power. That is, for every re-routing of links between physical acts and outcomes, there should be a "multiplier of effectiveness," a factor that makes the input effort more useful to the child than the previous method. For instance, if walking ten feet with crutches takes ten units of effort "perspirons," then driving a power chair the same distance should take five perspirons or so. In this way both input needs are lessened and outcomes are improved as a result of successful rehabilitation engineering interventions. The product is a child who not only gets to class on time, but is both less worn out from the trip and more confident of his or her control of cause and effect.

It is this last point, what is referred to as "locus of control," where rehabilitation engineering has much to offer. Through technology we can help transform feelings of powerlessness into ever-increasingly true beliefs of control originating from the self.

Where would we aim capabilities like this when referring to disabled children? The natural answer is to aim at substituting and assisting those functions thought to be primary in the development of non-disabled children. Notable among these are cause and effect, learning through manipulating objects in the environment, and play for psychological expression.

Following is a brief list and description of devices currently in use at Matheny School, all of which address one or more of the above points. The descriptions are not meant to be exhaustive or even sufficient for reproduction elsewhere, but are only intended to give an idea of the lines we are pursuing. Others are encouraged to contact us for more information and to offer their developments.

In using the devices with our students, therapists have noticed that some of the aids function well as evaluation and training instruments. This point should not be overlooked. Using play-oriented equipment for therapeutic purposes is a time-honored tradition that should be extended fully throughout rehabilitation engineering hardware and its incorporation into therapeutic programs.

DESCRIPTION OF DEVICES

Battery-operated Toys

We use a full range of battery-operated toys, externalizing the switches to large "paddle plates." We divide our toys into categories based on the number of switches required to operate them. We have one, two, and four switch toys. The most popular toy is a modified Electra-Doodle. This toy, commercially available, is a motorized version of the Etch-a-Sketch, and it has left, right, up, and down directions for forming an image. We externalize the switches and place them on a Velcro surface so they can be spaced appropriately for each child.

Play Crane

We are building an overhead crane for recreational use and an opportunity for the students to manipulate objects in space. The crane will cover a 12 by 16 foot area and will use an electromagnet to lift light cardboard boxes for the purposes of stacking, knocking over, etc. Again, the design is such that all switches will be modular and adjustable so that any student can use the crane.

"Truth Booth"

We have built a reactive environment, a learning booth relatively sealed off from distractions, wherein a student can activate switches of various sorts in order to get certain results. There is a half-silvered mirror that is angled at the student so that he sees his reflection. When the proper switch is hit, a light goes on behind the mirror, the reflection disappears, and whatever is in the "magic box" is revealed. There is a slide projector with modified switches for advancing and regressing a carousel. A typical program with this device would have the student looking through the slides to find one that matched an object in the magic box. The programmmatic possibilities are quite sophisticated when one considers that all switches can be either momentary or latching, and the tasks can range from simply scanning slides to performing complicated matching and sequencing tasks. There is an audio aspect as well, with similar controls. The exterior is attractively painted.

Pig Squirter

We have attached a replacement automotive windshield washer pump to a plastic pig in such a way that students can squirt each other or staff by depressing a switch. The range is quite good! This aspect of development, what might be called "acting out behavior" is important to keep in mind. Severely disabled children do not get much opportunity to "slam the screen door," and most of the behaviors they are capable of doing as aggression are regressive, such as biting, defecating, or refusing food. It makes good sense to offer other options. We are considering an adult-as-target water game for the warm months along the lines of "Dunk the Teacher."

Electric Wheelchairs

Electric wheelchairs are a central part of our rehabilitation engineering effort. We have a wide range of evaluation hardware as well as a set of protocols for therapists to use to determine good candidates for power chairs. Our wheelchair maintenance program offers same-day repair and preventive checks, as well as informing both students and staff about how the chairs work and why they fail.

Power wheelchairs offer students not only the obvious benefits of independent mobility, but increased interaction in general, showing up as more communication, more often self-initiated. Power chairs are also wonderful agression outlets, permitting the student opportunities to slam into both animate and inanimate objects with dramatic results.

CONCLUSION

If rehabilitation engineering is to make a significant contribution to the treatment of congenitally disabled children, it must address the developmental needs of those children. This requires education in both "normal" development and the underlying theories of treatment of the non-technical therapies. In this way, technical aids become not an end in themselves, but an effectively integrated method of treatment.

13.1

THE EFFECTS OF FIBULAR SHORTENING ON THE BIOMECHANICS OF THE ANKLE JOINT

G.W.Knight, A.G.Patwardhan, M.R.Zindrick, W.J.Gogan, R.Vanderby
Rehabilitation Research and Development Center
Hines VA Hospital, Hines, Illinois
Department of Orthopedics and Rehabilitation
Loyola University Medical Center, Maywood, Illinois

INTRODUCTION

Fractures of the ankle joint complex are a common orthopedic injury. The most common ankle injury is a supination-eversion injury (using the Lauge-Hansen classification system) (2). These injuries generally involve adults and result in time away from work as well as time for rehabilitation. Usually, the younger the patient, the more severe the injury and the more time required for rehabilitation.

The treatment of ankle fractures remains controversial, but it is generally agreed that the primary result is usually permanent and that the closer the anatomic reduction the better the functional result. In a study of 489 patients (5), 30% of the ankles treated conservatively (plaster reduction) and 12% treated by open reduction had imperfect reduction of the lateral malleolus. Yablon et al.(7) have shown that as the fibula is externally rotated the talus follows leaving a less efficient ankle joint due to the fibular malunion. It is this fibular malunion that has been clinically observed to lead to degenerative arthritis.

Various experimental techniques have been utilized in the past in an effort to quantitate the effects of fibular malunion on the biomechanics of the ankle joint. Contact areas and loading patterns have been measured with various staining techniques (3,4) and silicone rubber molds (1) under various loading conditions. These studies have all investigated changes in contact area following alteration of the anatomy of cadaver specimens to simulate malaligned ankle fractures. However, physiologic loads as seen in normal gait were not applied. This study attempts to further investigate this area by performing similar experiments but at physiologic loads. In addition, pressure distributions and peak pressures are recorded. The variations of these parameters are presented as a function of fibular shortening. Thus, this experiment attempts to quantitate what is an acceptable amount of fibular shortening by biomechanically evaluating simulated malalignment in cadaver limbs.

MATERIALS AND METHODS

Preparation of Specimens

Fresh cadaver specimens were used for this study. There was no previous history of ankle or lower limb trauma. The lower limb was disarticulated at the knee and at the talonavicular and calcaneocuboid joints. Soft tissue was removed but the interosseous membrane and all the ligaments around the ankle were left intact. Methylmethacrylate molds were made for the superior and inferior surfaces of the specimen. The ankle capsule was opened anteriorly and posteriorly to allow for placement of the pressure sensitive film. Following tests on the "normal ankle joint", a supination-eversion injury was simulated. A transverse osteotomy was performed on the fibula just proximal to the syndesmosis. The anterior and posterior tibofibular ligaments, the inferior transverse ligament, and interosseous ligament were divided. The deltoid ligament and lateral collateral ligament were left intact. There was no osteotomy of the tibia. The interosseous membrane was also divided up to the level of the osteotomy. A special four hole plate with spacers in the middle was applied to the fibula prior to the osteotomy. This plate allowed controlled positioning of the two fibula fragments. By removal of a spacer, shortening of the fibula was achieved.

Apparatus

The testing apparatus used were an Instron (model 1122) universal testing machine; Fuji Prescale pressure sensitive film; a Fuji Prescale Densitometer (model FPD 201); a film scanning device; and a planimeter. The Instron was used to apply a compressive axial load to the specimen in a controlled manner. Pressures in the ankle joint created during compressive loading were recorded using the pressure sensitive film. The densitometer then quantified the pressure imprints on the film using the scanning device to provide a uniform means of sampling the film. The scanning device consisted of an adjustable table for planar positioning and a vertically adjustable arm to lower the densitometer scanning head to the film surface. The planimeter was used to obtain the area of the pressure imprint; i.e., the contact area.

Experimental Methodology

Each specimen was tested in the neutral position at a compressive force of 1260 N (128 Kg). This force level was based upon data from an earlier study where it was reported that with the foot in neutral position during single limb support of the gait cycle, the force through the ankle joint was 1.8 times body weight (6).

Strips of the pressure sensitive film were cut to cover the entire surface of the ankle joint and then sealed in moisture-proof packets. The film packets were inserted between the articulating surfaces of the tibia and talus.

The specimen was placed in axial compression by lowering the crosshead of the Instron at a fixed strain rate of 2 mm/min. Once the desired load level (128 kg) was reached, that load was held constant for two minutes. The specimen was then unloaded by raising the crosshead at the same 2 mm/min rate. This procedure follows the guidelines for correct usage of the pressure sensitive film. The force-displacement curves were recorded during this load-hold-unload procedure. The film packets were removed and checked for moisture damage or artifacts due to mishandling. If the film passed this inspection it was then read using the previously described densitometer and scanning device. The specimens were tested at zero shortening(pre- and post-osteotomy) and at 2 and 4 mm shortening. For purposes of graphic representation, zero shortening at post-osteotomy is shown as 1 mm shortening although no shortening was apparent.

RESULTS AND DISCUSSION

In this experiment, measurements were taken when physiological loads across the ankle joint were applied in the neutral position. Results are shown in Figures 1-4. The anatomic variation studied was that simulating fibular fracture and malunion in shortened position. With fibular shortening, average contact area in the ankle joint varied among specimens (fig.1), although the average contact area demonstrated little change. It was also observed that contact area shifted laterally as shortening progressed. An increase was seen in the percent of load bearing by the superior talar dome and presumably less by the medial and lateral malleolar facets which were not directly measured in the experiment (fig.2). The average pressure borne by the talar dome increased approximately 25% as fibular shortening progressed (fig.3). Peak pressures increased by about 30% (fig.4). In all specimens, changes were seen in these parameters beginning with 2 mm of shortening. Therefore, this study suggests that slight anatomic alterations in the ankle joint produce substantial changes in the biomechanics of the ankle.

CONCLUSIONS

1) Prescale pressure sensitive film can be utilized to accurately measure in vitro the intra-articular conditions of the ankle joint.

2) Changes in the ankle loading pattern are seen with as little as 2mm of fibula shortening.

REFERENCES

1. Kimizuka, M., Kurosawa, H., and Fukubayashi, T.: Load bearing pattern of the ankle joint. Arch. Orthop. Trauma and Surg. 96:45-9, 1980.

2. Lauge-Hansen, N.: Fracture of the ankle. Arch. Surg. 60:957, 1950.

3. Ramsey, P.L., and Hamilton, W.: Changes in tibiotalar area of contact caused by lateral shift. J. Bone Joint Surg. 58A:356-357, 1976.

4. Riede, U.N., Shenk, R.K., Willenegger, H.: Gelenkmechanische Untersuchungen zum Problem der post-traumatischen Arthrosen in oberen Sprunggelenk. Langenbecks Arch Klin. Chir. 328:258-271 (1971).

5. Solonen, K.A., and Lauttamus, L.: Operative treatment of ankle fractures. Acta Orthop. Scand. 39:223, 1968.

6. Stauffer, R.N., Chao, E.Y.S., Brewster, R.C.: Force and motion analysis of the normal, diseased, and prosthetic ankle joint. Clin. Orthop. Rel. Res. 127:189-196, 1977.

7. Yablon, I.G., Heller, F.G., and Shouse, L.: The key role of the lateral malleolus in displaced fractures of the ankle. J. Bone Jt. Surg. 59A:169, 1977.

Rehabilitation Research and Development Center
Hines Veterans Administration Hospital
P.O.Box 20
Hines, IL 60141

Department of Orthopedics
Loyola University Medical Center
2160 South First Ave.
Maywood, IL 60153

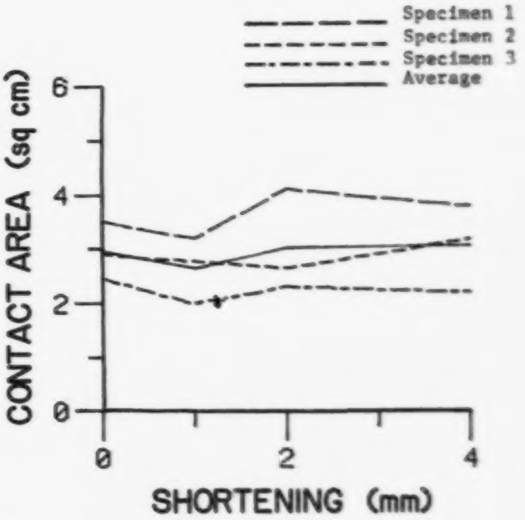

Fig. 1 - Changes in contact area between the tibia and talus during axial compression as fibular shortening increases. (The three specimens and their average values are shown in each of the following figures. A one mm shortening indicates post-osteotomy with no apparent shortening.)

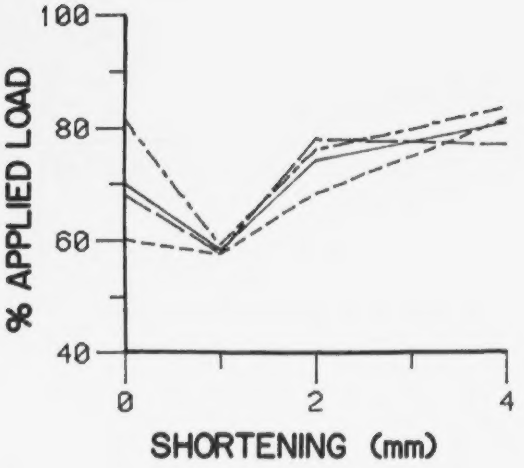

Fig. 2 - The load across the talus (expressed as a percentage of the applied load) vs. fibular shortening.

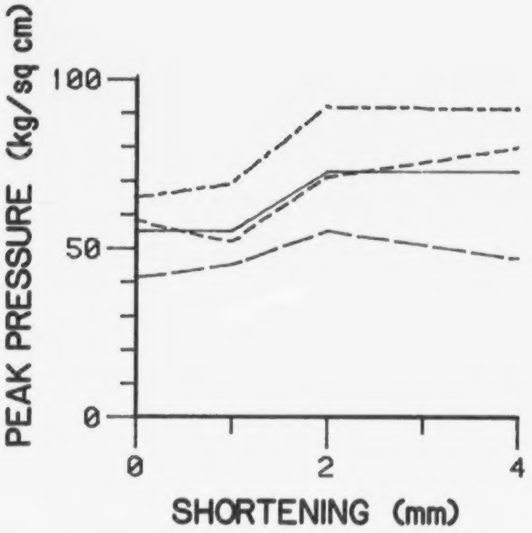

Fig. 4 - Peak pressure recorded across the surface of the talus vs. fibular shortening.

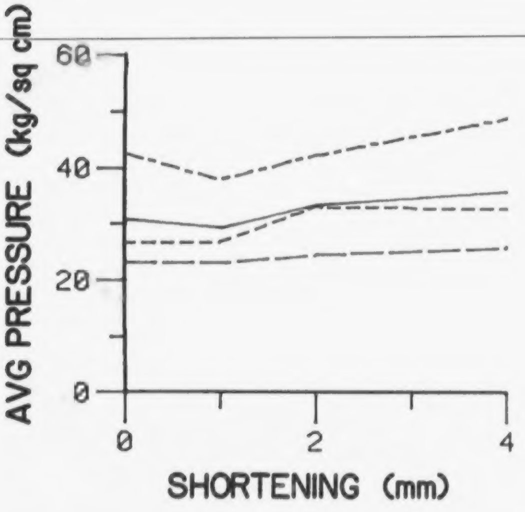

Fig. 3 - The average pressure across the talar surface vs. fibular shortening.

A PATIENT - SPECIFIC COMPUTER AIDED MODELING OF THE SPINE

R.L. Jennings, Ph.D., S.I. Reger, Ph.D., O.A. Morad, M.E. and K.C. Chung, M.S.

University of Virginia, Rehabilitation Engineering Center
Charlottesville, Virginia

INTRODUCTION

An orthopedic surgeon considering alternative reconstructive procedures for a fractured spine, would benefit from access to a computerized pre-operative technique which could evaluate the stability of each procedure. The research described here is addressed to the development of a first-level, patient-specific Computer Aided Modeling (CAM) of the spine.

The Computerized Model

The initial computer aided model of a section of the spine is based on the finite element model of a lumbar vertebral segment developed by Balasubramanian, Ranu and King (1). The one segment model of their work has been extended to a two-segment model connected by linear, elastic, one-dimensional elements (a rough model of disk and ligaments connecting the two bodies). A computer generated graphics display of the standard two-body model is shown in Figure 1.

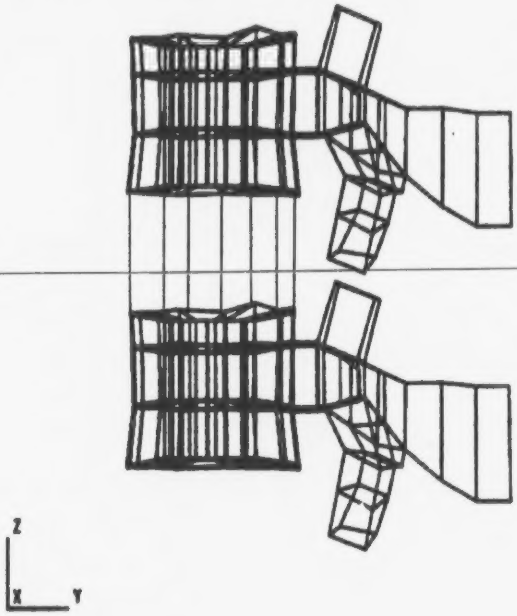

Figure 1 - The Standard Two-body Model as Modified After King's (1)

In this two-body model each vertebral body is composed of:

a) 124 "brick" (i.e. 8-node) elements representing the bony structure of the vertebra with the following material properties:

1. The spongy bone of the anterior structure:

   Poisson's ratio = 0.20
   Elastic Modulus = 0.36×10^6 psi

2. The compact bone of the posterior structure (lamina, pedicles, articular facets):

   Poisson's ratio = 0.25
   Elastic Modulus = 0.16×10^7 psi

b) 129" Plate or Shell" (i.e., 4-node) elements representing the end plates, the cortex, the spinous process and the transverse processes with the following material properties:

3. Poisson's ratio = 0.28
   Elastic modulus = 1.81×10^6 psi

The two vertebral bodies are connected by 20 one-dimensional (i.e., 2-node) elements that represent the intervertebral disk, ligamentous structure and musculature. The two bodies are presently only connected between end plates. More sophisticated connecting elements (3-D elements) will be introduced in the near future.

The present 2-body model has 526 structural "finite elements" that are defined by 527 nodes. The number of degrees of freedom of the system is reduced from 3162 (i.e., 6 x 527) to 2014 by assuming bilateral symmetry and by constraining the nodes of the inferior end plate of the lower body (simulating restraint provided in laboratory tests when lower body is embedded in a rigid methacrylate base). Thus each increment of load applied to the model requires the solution of 2014 simultaneous linear equations (bandwidth of 1110 equations). This large number of equations consumes large amounts of computer processing time, but is necessary in order to permit studying the development of fracture paths through the body as well as to permit accurate calculation of localized stresses in the bone.

The translations of each node in the x,y,z directions are computed by the finite element program. Additional software is used to permit the addition of these nodal translations to the original x,y,z coordinates of each node. This process produces the x,y,z coordinates of each node in the deformed configuration - data which is plotted and displayed on the terminal for visualization by the surgeon. The display package permits the surgeon to view the stressed bodies from different perspectives by use of simple interactive instructions.

The geometry of each vertebra of the standard two-body model is then proposed to be refined by patient-specific data. This real information is obtained by automatic processing of the patient's CAT (Computer Assisted Tomography) scan data, taken from the spine at pre-selected "slice" thickness.

An initial study of the CAT scan (Scan-2020 manufactured by Ohio Nuclear, Inc.) file structure, stored on magnetic tapes, showed that the geometry of an image of the scan could be automatically extracted and displayed on a graphics terminal. Figure 2 shows a typical x-ray image produced by the Cat Scanner.

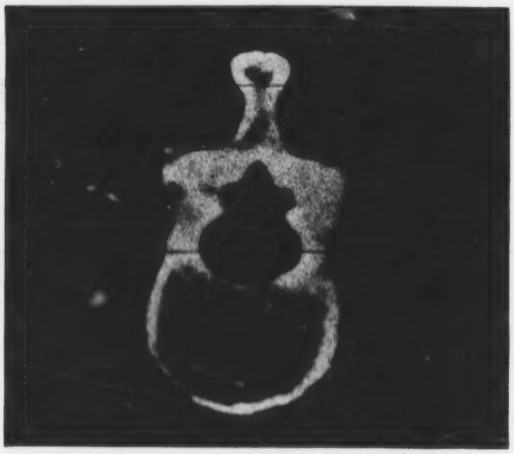

Figure 2 - A Typical X-ray Image Produced by a Cat Scanner

The typical x-ray image of Figure 2 is constructed from a 512 x 512 matrix of pixel information. Each pixel represents the x-ray attenuation coefficient pertaining to its position in space. If the processed image of Figure 2, consisting more than 250K pixels was used for input to a finite element code, the analysis of such large number of pixels as nodal points in the mesh network of the code would have required enormous computing power. A reduction in the data was, therefore, needed without the loss of the specific geometry.

The geometry of the vertebral image was displayed from Figure 2 by determining the attenuation coefficient of the compact bone. The coefficient was then used as a threshold in the display of the vertebral portion of the image. The rest of the pixels with attenuation coefficients below the threshold, were defined to be non-compact bone structure and discarded. Table 1 shows the relationship between the threshold value and the number of pixels displayed.

Table 1

Number of pixels/image as a function of the threshold value

Threshold (attenuation coefficient, dimensionless)	Number of Points (on the inner and outer perimeters of the image of Fig. 2)
1414	1209
1465	1018
1485	1006
1505	978
1525	956
2010	248
2015	248
2025	246

Further reduction in the data was accomplished by selecting for display only those pixels which are on the inner and outer perimeter of the vertebra. A graphical representation of the result is shown on Figure 3. In this image there remains approximately 1200 pixels.

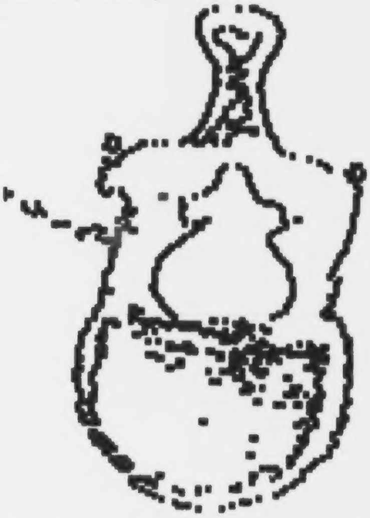

Figure 3 - A Computer-Generated Display of the Image of Figure 2

This many pixels are still considered excessive for economic input to a finite element analysis. Further data reduction is underway in which the number of pixels per image or "slice" will be reduced to approximately 200 while still retaining adequate individual representation of crossectional geometry, see Figure 4.

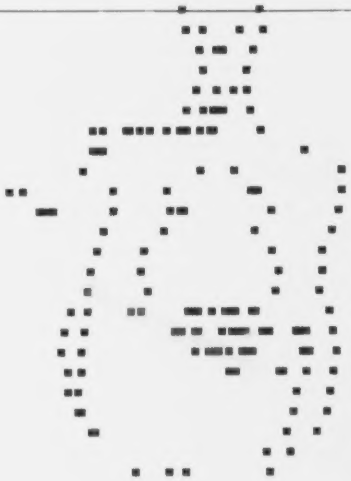

Figure 4 - Further Reduction of Pixel Numbers from Figure 3

Three or four slices of successive scans per vertebra, reduced in the manner described above will result in a compatible number of pixels as the nodes in the mesh network used in the King's model (1).

Validation of the Computer-Aided Model

Parallel work is also under way to develop algorithms that would automatically convert x-ray attenuation data to bone and ligament strength indexes. If this effort is proved successful, future levels of the spine model will permit automatic generation of patient-specific bone and soft tissue data as well as spinal geometry data. Preliminary efforts to validate the algorithms are being considered by experimental load tests on canine spines. Typical results shown in Figure 5 illustrate the load-deformation characteristics of a two vertebral segment of the cervical spine before and after transverse section of the intervertebral disk.

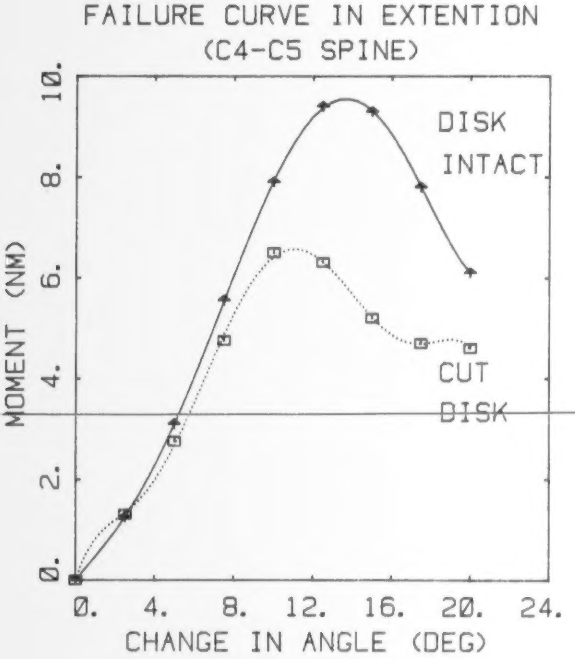

Figure 5 - Experimental Results for Verification of the Computer Aided Modeling of the Spine Segment

Future Work

It is the long-range objective of this project to develop a computerized system that would permit the surgeon, prior to surgery, to:

1. Display on a graphics terminal a representation of a section of the patients spine that will be operated on;
2. Simulate surgical procedures by use of light pen or keyboard to:
    (a) Delete segments of bone or tissue (resections)
    (b) Add segments (wire,rod as used in stabilization)
3. Subject the simulated stabilized spine to static loadings on the computer that would test the strength of the elements of the surgically - repaired spine. This would be accomplished by use of a finite element program (we are presently using SAP-IV refer to Reference 2).
4. If the behavior of the re-constructed spine from steps 2 and 3 (above) is unsatisfactory, return to step 2 and simulate an alternative surgical procedure.

The present model of the human spine is based on a linear, elastic lumbar element. Subsequent research may be directed toward:

1. Incorporating non-linear tissue properties.
2. Extend to cervical and thoracic elements so the entire spine can be utilized.
3. Improved modeling of the disk and ligaments.

REFERNECES

1. Balasubramanian, K., Ranu, H.S. and King, A.I., "Vertebral Response to Laminectomy," Journal of Biomechanics, Vol. 12, pp. 813-823,

2. "SAP IV - A Structural Analysis Program for Static and Dynamic Response of Linear Systems," Report No. EERC 73-11, College of Engineering, University of California, June 1973.

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Richard L. Jennings, Ph.D.
Rehabilitation Engineering Center
P.O. Box 3368, University Station
Charlottesville, Virginia 22903

13.3

ORGANIZATION OF A CONTROL SYSTEM FOR A MANIPULATIVE AID

C. E. Buckley
Stanford University and
Palo Alto VA Hospital

ABSTRACT

The man-machine interface requirements of a robot aid for high quadriplegics are described. The organization of a control system to manage this interface that is capable of fully representing the dynamic system being controlled is described, and compared with standard methods of robot control.

The organization described, called UNIACSYS[1], is the basis for a manipulator control system currently being implemented in cooperation between Stanford University and the Palo Alto Veterans' Administration Hospital.

INTRODUCTION

The development of a manipulative aid for the severely disabled has been undertaken by many researchers spanning a period of the last 20 years [1-5]. Readers seeking to develop an appreciation of the desirability of this goal, or who want to to become acquaint themselves with recent work done in this area are referred to the entire volume containing reference [4].

This paper provides a review of the requirements of a manipulative aid interfacing a disabled operator to the nearby environment. It goes on to describe an organization for a control system that will meet these requirements, a version of which is currently being implemented. This work is continued from work begun with a previous implementation, as described in [6].

BACKGROUND

The Importance of the Interface Problem

The problems being researched in the development of robot manipulator aids for the disabled fall into two main categories:

1. development of a manipulator which is mechanically compatible with the living environment of the disabled user.
2. development of a flexible interface whereby such a device may be used to perform activities not anticipated by system designers.

Previous researchers have undertaken primarily to attack the first category with lesser emphasis placed on the second. Resulting of this strategy has been some well engineered devices adept at execution of a set of anticipated tasks, but maladroit or incapable of others. Some of these devices rely heavily on being used in a structured environment [1,5].

Therefore, manipulative aid research at the Palo Alto VA Hospital is concentrated on the development of a useful man-machine interface. For expediency in experimentation, industrial manipulators are used as stand-ins for an anticipated custom-designed device.

Types of Control

Control signals transmitted from one entity in a system to another may be of two types. Here, the terminology of Sheridan is used [7]:

analogic: where the value passed is a member of a dense, ordered domain in which the time history of values is isomorphic with the time history of some controlled variable in the system. Examples: joysticks, force feedback

symbolic: where the value represents one element of a countable set domain, whose members are not constrained by order or neighborhood. Examples: switches, text

Work with analogic control of manipulators was pioneered by Goertz [8], for remote handling of radioactive waste. Symbolic control is used primarily for systems which can be represented by finite-state machines, such as the memory of computers, or for industrial manipulation tasks of restricted scope.

Such control signals may come either from a human operator, as was the case with Goertz' teleoperators, or from a computer, as is done with industrial manipulators. Sheridan introduced the concept of mixing the two; using a computer and human operator in concert to cover each other's deficiencies. He termed this practice "supervisory control" [9]. Brooks has applied supervisory control concepts to a master/slave manipulator similar to that used by Goertz [10].

Assay of the Human/Computer/Environment Interface

A block diagram of the interface between an operator, a manipulator, and the manipulated environment is shown in Figure 1, with major classes of channels along which information is transmitted marked by arrows and labeled.

A summary of the characteristics of the these paths is presented in Table 1. Note that the "robot manipulator" has been relabeled "computer" in the table. A computer-controlled robot manipulator is properly considered as a peripheral of its controlling computer, converting binary patterns to manipulation, much as a line printer converts binary images to printed characters.

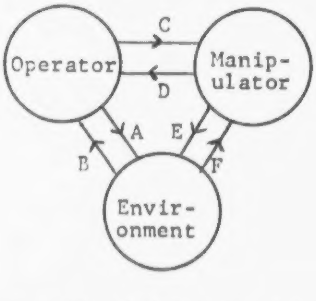

Figure 1: Disabled Operator Interface

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[1] for UNIfied Arm Control SYStem

Path	Analogic	Symbolic
op.=>env. [A]	limited (mouthstick)	none
env.=>op [B]	visual reckoning catastrophes (body collisions)	auditory and visual perception
op.=>comp. [C]	2-4 degrees of freedom	voice command special switches
comp.=>op. [D]	force feedback graphic display	symbolic display
comp.=>env. [E]	manip. degrees of freedom	none (excluding special cases)
env.=>comp. [F]	sensor degrees of freedom	finite state sensors

Table 1: Characteristics of Information Channels

Note the limited number of analogic channels not only from the operator to the environment (i. e. none), but from the operator to the computer.

INTERFACE DESIGN

Design Considerations

There seems little question that it is desirable to provide the disabled operator with means of executing both symbolic and analogic control over a manipulative aid. The concept of an intelligent robot which understands and carries out orders issued to it conversationally (full symbolic control) has broad popular appeal, but the primitive state of development of artificial intelligence precludes the reduction of such systems to practice within the forseeable future.

For the present, it remains necessary to use the operator to null out position errors. That is to say, at times it will be necessary to put the "man-in-the-loop". Analogic signals have traditionally been used for this. However, given the limited number of analogic degrees of freedom at the disposal of the handicapped operator, a symbolic channel of communication is also required to permit multiplexing, and to provide meaning to the analogic signals transmitted by the operator.

The question of assignment of specific duties to the different types of control also remains open. Although analogic inputs to controls signals have traditionally been reserved for regulation, it is possible to use them for entry of symbolic data, through comparison with thresholds. For example, a joystick may operate as a joystick causing two degrees of freedom of a manipulator to servo on position, yet an increase in rate above a certain threshold may indicate a desire by the operator to freeze the manipulator in its current position, to permit other things to happen.

Likewise, under certain conditions, symbolic commands may substitute for analogic control [6]. Sensor data may also be used for both purposes.

It is therefore important that a control system for a manipulative aid not categorically relegate available information to use only in specific categories. Otherwise, major changes in the nature of hypotheses being tested require that the research manipulator control system be designed over again, which is time-consuming and costly.

Standard Control Systems

The control of robot manipulators has been traditionally organized around some sort of manipulation language, which are extensions of problem-oriented languages developed for "scientific" computing.

One example of such a language is AL [11], which is an extension of Algol to cover things such as special data types and environmental modelling. Other manipulator programming languages are PAL [12], AML [13], and LAMA-S [14].

Statements in these traditional programming languages operate in a context in which a set of implicit conditions apply. A partial list of these implicit conditions is given in Table 2.

- statements execute sequentially
- knowledge of the internal state of the computer at the beginning and end of a statement is sufficient for stating what the action of that statement is (i. e. no hidden modes)
- the time of execution per statement is significantly faster than any event of importance to the computer
- no activity is performed in between statements

Table 2: The Context of Traditional Programming Language Statements

Such languages can be and have been applied to manipulation in ways that violate the context described in Table 2. For example, consider a robot manipulator language statement 'MOVE', which causes a robot manipulator to move from rest at one position to another, ending up at rest.

The execution of this statement may take on the order of seconds to complete, if acceleration constraints are imposed. Significant events, such as collisions, may occur during the statement. There are many trajectories which may be followed in movement from the start to the endpoint. Some of these may not be possible to execute. Finally, the manipulator positon must be regulated even between statements.

These observations would suggest that the definition of an endpoint-directed motion as an atomic statement of a manipulator language is inconsistent with the context of such a statement. Yet, the manipulator control languages cited above have such statements. In these cases, inconsistencies are resolved through control of the manipulation environment, so that obstacles are not a problem, and through insulation of the manipulation language from the physical world using auxiliary servo loops. This is expedient, but prevents the manipulation language from being being able to describe a large class of useful tasks.

The language LAMA-S, in recognition of this shortcoming, has been extended to include a set of so-called "real-time primitives". These primitives are blocks which are functionally equivalent to a statement. Within these blocks, statements which come closer to satisfying the context outlined in Table 2 are executed repeatedly until some exit criterion is met [14].

State-Space Control System

It is argued that the real time primitives found in LAMA-S are isofunctional to the integration of the canonic state-space representation:

$$\dot{x} = f_i(x,u,t)$$

where

x is the state vector of the system
u is the vector of control inputs
t is the variable for time
f is the selected state space relationship which may be changed periodically, according to certain indicator states, which are part of the state variable vector x

It is further submitted that representation in the state space form is advantageous, because:

- rate of the calculations are synchronized around a known clock rate
- it takes advantage of a well-developed set set of theory concerning system behavior
- techniques for direct control design in the discrete domain have already been developed
- the external model of computer activity closely agrees with the internal model
- optimization of calculations and horizontal distribution of load to multiple processors is facilitated

Table 3: Advantages of the State-Space Control

Under the UNIACSYS formalism, atomic statements in a manipulator language are replaced by action periods, in which difference equations designed to perform a particular activity are integrated. These action periods may take an indeterminate amount of time, integrating until a threshold is crossed by some element of the state vector. Conditional branching among action periods is performed on the basis of which state crossed which threshold first. Computer-generated trajectories are represented as control inputs to the difference equations.

Examples of the kind of thing for which an action period is designed are to servo manipulator degrees of freedom according to joystick degrees of freedom, or keep the end effector of a manipulator pressed against a surface with constant force.

The suitability of this formalism in dealing with analogic control signals is obvious. Symbolic control signals are also easy to deal with. An example of use of symbolic inputs is described in [6]. In this example, voice commands indicating a direction of motion (ABOVE, BELOW, LEFT, RIGHT, STOP, etc.) were converted to cumulative additions to a velocity vector. This vector was in turn use as part of an input ensemble in an action period.

Space does not permit inclusion of further details.

CONCLUSIONS

A non-standard control system for a manipulative aid has been outlined. Preliminary results using a partial implementation of this system have shown promise of increased flexibility in operator control.

Based on these results, a more complete implementation of the system described in this paper is currently in progress to perform clinical study of the relative merits of this system.

ACKNOWLEDGEMENT

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REFERENCES

1. Schneider, W., Schmeisser, G., and Seamone, W., "A Computer-Aided Robotic Arm/Worktable System for the High-Level Quadriplegic", IEEE Computer, Vol. 11, No. 1, Jan. 1981, pp. 41-47
2. Apple, H. P., and Reswick, J. B., "A Multi-Level Approach to Orthotic/Prosthetic Control System Design", in Advances in External Control of Human Extremities, ETAN, Belgrade, 1970
3. Guittet, J., Kwee, H., Quetin, N., and Yclon, J., "The Spartacus Telethesis: Manipulator Control Studies", Bulletin of Prosthetics Research, 10-32, Fall 1979, pp. 69-105
4. Bejczy, A. K., "Voice Command System for Motion Control", International Conference on Telemanipulators for the Physically Handicapped, Roquencourt, France, September 1978, pp. 103-116
5. Roesler, H., and Paselack, V., 'Manipulators for Tetraplegics in adapted Environments', Second CISM-IFToMM Symposium on the Theory and Practice of Robots and Manipulators, Elsevier, Amsterdam, 1977, pp. 384-393
6. Buckley, C. E., and Leifer, L. J, "Fast Interactive Control of a Manipulator for the Severely Disabled', Proceedings of the 1982 American Control Conference, pp.1195-1198
7. Sheridan, T. B., and Verplank, W. L, "Human and Computer Control of Undersea Teleoperators", Massachusetts Institute of Technology Man-Machine Systems Laboratory Report, July 15, 1978, p. 5-19
8. Goertz, R. C., and Bevilacqua, F., "A Force-Reflecting Positional Servomechanism", Nucleonics, Vol. 10, No. 11, pp. 43-45
9. Op. cit., p. 1-1
10. Brooks, T. L., 'Superman: a System for Supervisory Manipulation and the Study of Human/Computer Interactions", Massachusetts Institute of Technology Man-Machine Systems Laboratory Report, May 11, 1979.
11. Mutjaba, S. and Goldman, R., AL Users Manual, Stanford AI Lab Memo. No. AIM-344, December 1981.
12. Takase, K., Paul, R. P., and Berg, E. J., "A Structured Approach to Robot Programming and Teaching", IEEE Transactions on Systems, Man, and Cybernetics, Vol. SMC-11, #4, April 1981, pp. 274-289
13. Grossman, D. D., 'Robotics Software at IBM", proceedings of the 2nd Annual International Computer Engineering Conference, Aug. 15, 1982, Vol. 2, pp. 73-75
14. Falek, D. and Parent, M., "LAMA-S: an Evolutive Language for an Intelligent Robot", Industrial Robot, Vol. 7, #3, pp. 168-171.
15. Wampler, C. W., Buckley, C. E., Jameson, J. W., and Leifer, L. J., "A Sensate Hand for Interactive Manipulation", 1983, submitted to ASME Journal of Mechanical Design

Address correspondence to: C. E. Buckley, Design Division, Stanford, Cal. 94305

AUTOMATIC GRIPPING BASED ON TACTILE SENSATION

John Jameson
Palo Alto Veterans Administration Medical Center
Rehabilitative Research & Development Center

ABSTRACT

In the implementation of robotics for the severely handicapped, a need for automatic grasping is recognized. A method is presented here that relies solely on tactile feedback and does not require geometric modeling for the objects to be grasped. The process of grasping is treated as an optimization problem with the function to be maximized relating to the "quality" of the grasp. This function, called the Gripping Goal Function (GGF), depends on the configuration of the gripper, the expected loads on the object, and locations of contact points between the object and the gripper. By allowing the gripper to move about the object while maintaining light contact, an optimum search direction is given by the gradient of the GGF with respect to freedoms in the manipulator/gripper system.

INTRODUCTION

This work is part of a continuing effort to supply the severely handicapped with some means to control their environment without the need of human assistance. One aspect of this autonomy hinges on the ability to retrieve and manipulate objects, and towards this goal an industrial manipulator, with a suitable gripper, can be applied. Manual control of these devices can be extreemly tedious and time consuming, however, especially when the communication between man and machine is, for example, through voice commands or head motions.

When the task is retrievel of a particular object by a manipulator under manual control, it has been realized [1] that approximately seventy percent of the time involved for the task is taken up during the fine motions when the gripper is near the object. For a handicapped person exerting manual control, this particular phase of the task indeed imposes intolerable spans of attention, or may even be impossible if he cannot view the object properly.

It is in light of this that the need of an automatic gripping system is indentified. Such a system would "take over" the manipulator once the gripper has been placed in the general locale of the object. The gripper then automatically establishes contact with the object, and then "feels around" it until an adequate grasp has been found, thus relieving the user of the most time-consuming aspect of the task.

BACKGROUND

There are four basic ways today that robots sense there enviroment: (a) vision, (b) range "imaging" (eg. laser scanning or stereo vision), (c) proximity, and (d) tactile sensing. These four approaches have also been investigated for automating grasp [10,11]. Vision and ranging may ultimately play the greatest role in this endeavor as they allow the capability of guiding the gripper to the object as well as providing information necessary to determine suitable positions of the gripper for effective grasping. Present technology in this area, however, has not reached the degree of sophistocation required for the relatively unstructured environment of a home or office. Such systems are inherently very expensive, and require tremendous amounts of software to perform such functions as modeling of the environment, object recognition, and so forth.

Proximity sensing has been tried frequently in industry [5,6] and some in rehabilitation [1]. In this case a sensor indicates the distance to some part of an object's surface, with a range of detection on the order of one inch. These sensors have been used to automate grasp to some extent. Usually, though, they have only served the purpose of detecting whether or not an object is "in it's grasp" - a sort of binary evaluation of the grip to be executed. In view of this, it's not surprising that these approaches have also lacked a general and consistent strategy for seeking effective grasps.

Tactile sensing elements or arrays have been integrated into grippers with spatial resolutions varying from one element covering the whole gripping surface (common) to several hundred per square inch [4]. They have been employed with basically two separate goals in mind: object detection and object recognition [7,8,9]. Even so, applications today have not gone much beyond detecting the object's presence once the gripper has closed.

PREFERED APPROACH

Because of the expense and complexity associated with vision and range scanning, a means of automating grasp with tactile and proximity sensation is investigated here. Although the theory to be outlined is more appropriate with tactile sensation, the actual implementation is more suitable with (close range) proximity detection. This is simply because of the difficulty in finding touch sensors with sufficient sensitivity, and controls that are supple enough, to allow scanning about the object. (Try scanning an empty styrofoam cup with your own hand to get an idea of the difficulty. Keep in mind that your hand is a very sophisticated piece of "hardware".) In terms of mechanical hardware, the author has currently under development sensitive and durable "whiskers", which might be considered hybrids between proximity and tactile sensation.

OUTLINE OF OPERATION

An Automatic Gripping System (AGS) is proposed that would enable a robot gripper, or "hand", to automatically seek an effective grasp of any of a large class of objects. Utilizing tactile (or a hybrid with proximity) sensation, finger position, and wrist force feedback, the AGS would be capable of assessing the effectiveness of a current grasping configuration. The single numerical quantity assigned to this assessment is called the Gripping Goal Function (GGF) because it is a function to be maximized. That is, the maximum of the GGF corresponds to the "best" grasp over all possible grasps for a particular (gripper-object-environment) situation.

The AGS also determines the most expedient way to increase the GGF once initial contact is established, and does so continuously while the gripper is scanning. This is done by predicting increments in the GGF for virtual incremental displacements of the manipulator/gripper system. In mathematical terms this is called the "gradient" of the GGF.

An inherent difficulty with an optimization approach such as this is the hazard of getting stuck at a "local maximum". That is, at some point the AGS will determine that no more motions will improve the GGF. It may be the case, however, that a better grasp may be found elsewhere. The situation is analogous to standing on top of a small hill when you really want to be on top of a larger hill across the valley.

Since the grasp is considered sufficient when the GGF is above a predetermined value, it is not even required that we be at a maximum, as long as the GGF is above this value. If the case is, however, that we are at a local maximum and the GGF is not above this value, the gripper must be moved in some heuristic manner (while scanning) such that it may approach a more favorable optimum. Continuing the analogy, it must try to "leap across the valley".

Despite the problem of local maximums, it is hoped by the author that the AGS will be able to automatically grasp (effectively) many common objects without making these "heuristic leaps".

EXAMPLE

An example is now given which represents the most simple configuration required for supporting a rigid body when only point contacts with friction exist between the gripper and the object. If there is no slip, these contact points can be viewed kinematically as ball and socket "joints", and only three such contacts are required to secure the object.

Figure (1) shows a three link gripper with a revolute joint connecting each link to the "palm". Mobility analysis [3] reveals that such a configuration is immobile regardless of the joint torques. This assumes that there is no slip at the contacts, and that a few special configurations are avoided (these special configurations do not pose a threat in the final calculations, however).

Figure (2) shows the resultant force, f, acting at a contact point where the surface normal (unit vector) is n. If f is broken into two components, one parallel to n (f_n) and the other tangential to the surface (f_t), the requirement for no slip is $f_t < u\, f_n$, where u is the coefficient of static friction. This transforms into the relation

$$q \geq [\ 1 + u^2\ ]^{-1/2}, \qquad (1)$$

where q is defined as cosine of the angle θ shown in figure (2).

Figure 1

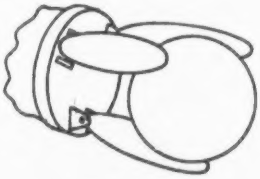
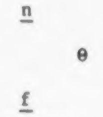


Figure 2



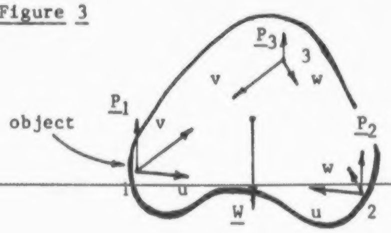
Thus, the requirement for no slip at any of the contact points, and thus for a secure grasp, is

$$q_1, q_2, q_3 \geq q_c\ , \qquad (2)$$

where q_c is given by the expression in eq. (1).

To find the resultant forces at the contact points, we use laws of static equilibrium. A nice approach is outlined by Salisbury [3] using the "wrench system". The geometric result is shown in figure (3), where the load is considered only to be the weight of the object. The vectors $\underline{P}_1$, $\underline{P}_2$, and $\underline{P}_3$ are the particular solutions that account for $\underline{W}$, chosen to be aligned with it. The quantities u,v, and w are magnitudes of the internal forces, which act along lines connecting the contact points. These forces are self-cancelling and thus can have arbitrary magnitude without altering equilibrium. Thus, resultant forces at the contact points are

Figure 3



$$\underline{f}_1 = \underline{P}_1 - u\ \underline{x}_{12} - v\ \underline{x}_{13} \qquad (3a)$$

$$\underline{f}_2 = \underline{P}_2 + u\ \underline{x}_{12} - w\ \underline{x}_{23} \qquad (3b)$$

$$\underline{f}_3 = \underline{P}_3 + v\ \underline{x}_{13} + w\ \underline{x}_{23} \qquad (3c)$$

where unit vectors $\underline{x}_{12}$, $\underline{x}_{13}$, and $\underline{x}_{23}$ are along lines connecting the contact points.

The expression for each q_i is

$$q_i = -\ (\underline{f}\cdot\underline{n}_i\ /\ |\underline{f}_i|),\ i = 1,2,3. \qquad (4)$$

which, upon substitution from eq. 3, becomes

$$q_1 = [\ A_1(u,v)\ /\ B_1(u,v)\ ]^{-1/2} \qquad (5a)$$

$$q_2 = [\ A_2(u,w)\ /\ B_2(u,w)\ ]^{-1/2} \qquad (5b)$$

$$q_3 = [\ A_3(v,w)\ /\ B_3(v,w)\ ]^{-1/2} \qquad (5c)$$

where A_i and B_i (i=1,2,3) are quadratics.

The condition for a secure grasp can now be defined more precisely as

$$\max_{u,v,w} [\operatorname{Min} (q_1,q_2,q_3)] \geq q_c . \qquad (6)$$

In other words, if the maximin is less than q_c, there is no combination of the internal forces (u,v, and w) for which q_1,q_2, and q_3 are all greater than q_c. Thus, the object will slip.

It can be shown that the relationship between the internal forces and the joint torques is

$$\underline{u} = G^{-1}\underline{u} + \underline{P}, \qquad (7)$$

where G^{-1} is a 3X3 matrix of constants, and $\underline{u}$, $\underline{t}$, and $\underline{P}$ are vectors containing the internal forces, the three joint torques, and three constants, respectively.

In this case it is possible to substitute the expressions for u,v, and w obtained from eq. (7) into eqs. 5, yielding equations of identical form, but with t_1,t_2, and t_3 in place of u,v, and w. Defining

$$q^* = \max_{t_1,t_2,t_3} [\operatorname{Min} (q_1,q_2,q_3)] , \qquad (8)$$

the requirement for no slip is $q^* \geq q_c$, but now with the constraints $t_i \leq t_{mi}$ (i=1,2,3), where t_{mi} corresponds to the maximum torque for each t_i.

Since q^* is a measure for incipient slip, it is a good candidate for the GGF. However, the preceeding analysis considered the load to be only the weight, but in practice there will probably be other loads which occur during a task. This should be taken into consideration in construction of the GGF. To motivate the discussion, however, let us define the GGF to be q^*.

The assertation of a best direction for the gripper to search thus involves calculating the gradient of q^* ($\underline{\nabla q}^*$) with respect to all "non-scanning" freedoms of the manipulator/gripper system. For the case of figure (1), all links of the gripper must serve to scan, and thus their positions do not show up as elements in $\underline{\nabla q}^*$.

Note that the controls required to make the "fingers" scan can be implemented independently of any other logic, offering the possibility for parallel processing (greater speed).

FUTURE WORK

The author first intends to model grasping tasks with computer simulations, representing objects as cubes, cylinders, and other (more complex) shapes. This will offer a verification of the present theory, as well as suggesting directions for gripper design, without first constructing hardware. If simulations reveal promising characteristics of the proposed AGS, an actual prototype system shall be constructed.

The example presented above represented a simple, statically determinate system. Work is presently under way (by the author) to determine requirements for grasp security with more than three contacts, which generally involve statically indeterminate systems.

Supported by Rehabilitative Research and Development Center, Palo Alto VAMC, Palo Alto, California 94304.

REFERENCES

[1.] Leifer, L., Sun, R., and Van der Loos, H. F. M., "A Smart Sensate Hand for Terminal Device Centered Control of a Rehabilitative Manipulator", 1980 Advances in Bioengineering, V. C. Mow, editor, ASME, New York, pp. 69-72, 1980.

[2.] Hanafusa, H., and Asada, H., "Stable Prehension by a Robot Hand with Elastic Fingers", Proc. 7th Int. Sym. on Industrial Robotics, Tokyo, Oct. 1977.

[3.] Salisbury, J. K., "Kinematic and Force Analysis of Articulated Hands", Ph.D. Dissertation, Dept. of Mech. Engineering, Stanford University, 1982.

[4.] Hillis, D. W., "A High Resolution Imaging Touch Sensor", Int. Journal of Robotics Research, Vol. 1, No. 2, Summer 1982.

[5.] Harmon, Leon D., "Automated Tactile Sensing", Int. Journal of Robotics Research, Vol. 1, No. 2, May 1982, MIT Press.

[6.] Hanafusa, H., Asada, H., "An Adaptive Control of Robot Hand Equipped with Pneumatic Proximity Sensors", 6th ISIR, March 1976.

[7.] Briot, M., "The Utilization of an 'Artificial Skin' Sensor for the Identification of Solid Objects",9th ISIR, March 1979.

[8.] Hillis, W. D., "Active Touch Sensing", Master Thesis, MIT Jan. 1980.

[9.] Ozaki, H., Waku, S., Akira, M., Takata, M., "Pattern Recognition of a Grasped Object by Unit-Vector Distribution", IEEE Trans. on Sys., Man, and Cyb., Vol. SMC-12, No. 3, May/June 1982.

[10.] Sugiyama, K., Matsuzaki, A., Nabeshima, Y. Hibino, Y., "Automatic Container Handling Device with Tactile Sensor", 7th ISIR, Oct. 1977.

[11.] Laugier, C., "A Program for Automatic Grasping of Objects with a Robot Arm", 12th ISIR, March 1982.

13.5 A TREATMENT COMPATIBLE TRANSPORT SYSTEM FOR SPINAL INJURY PATIENTS

Frank Selker, Tim Dirstine, and Conal Wilmot

Palo Alto Veterans Administration Medical Center
Rehabilitation Research and Development Center

ABSTRACT

A special spineboard is being developed which reduces the risk of trauma to cervical spine injury patients during transportation and treatment. The stabilization transport system (STS), with adjustable spring traction unit, is to be compatible with transport equipment, computed tomography (CT) scanners, standard radiographic equipment, and hyperbaric chambers. These features will greatly reduce the need to interrupt traction or transfer patients between equipment during transportation or treatment.

INTRODUCTION

Moving or treating patients who have cervical spine injuries can involve significant risk of spinal cord trauma due to stress or pressure on the cord. Such stresses may result from interruption of traction, bending of the neck associated with head motion, or both. Three common occasions on which patients are exposed to these risks are: 1) transportation between hospitals, 2) transportion within hospitals, and 3) transfers to and from x-ray machines, CT scanners, and hyperbaric chambers. As well as reducing the risk during each of these three procedures, there is a synergistic advantage in combining these functions; for example, in addition to providing stabilization during hyperbaric treatment and transportation, the need for transfers between these is eliminated.

There is a need for a device which reduces the risks during these three procedures. This need was noted locally by Santa Clara Valley Medical Center (base if the Northern California Regional Spinal Cord Injury System), which sees about 60 acute cervical spine injury patients annually. At their request for an improved system, we undertook the development of the STS. Since there are about 4000 cervical spine injury patients each year, many patients could benefit from such a device.

FUNCTIONAL REQUIREMENTS

The following are the functional requirements of a system which will minimize risks to the patient:

1) The STS should include a lightweight and adjustable traction unit, which must not interfere with other functions. The traction force vector should be adustable from about 5 to 25 lbs, and from 0 degrees (in line) to 30 degrees anterior in the anterior-posterior plane [1]. The traction force must also remain constant during the motion and tilting associated with transportation treatment.

2) The STS must be radiolucent (i.e. transparent to x-rays) enough not to interfere with the images of standard radiographic equipment or CT scanners. This requires attention to shape and to density variations, as well as to the use of radiolucent materials (low atomic weight and low density).

3) The STS must withstand 3 atm absolute pressure of pure oxygen in the hyperbaric chamber. Due to the fire hazards of the high-oxygen atmosphere, it must be constructed of non-sparking, flame-resistant, and conductive, anti-static materials.

4) The STS must fit into common hyperbaric chambers, CT scanners, x-ray machines, ground ambulances, and air ambulances.

5) The STS must provide comfortable and secure head restraint. As well as preventing head motion, the head restraint system must not interfere with traction or imaging.

6) The STS should be padded so that it is comfortable and safe during extended treatments or transportation; it should not cause bed sores for stays up to 12 hours.

7) The STS should have the characteristics of a good conventional spineboard: it should be lightweight, durable, cleanable, easy to handle, and easy to operate.

BACKGROUND

While devices have been built for each of the three procedures addressed (transport between hospitals, transport within hospitals, and use with treatments and diagnostics), none has been designed for all three together [2]. Thus nothing exactly like the STS is currently in use. Devices which are used for each of the three procedures are reviewed below.

Several systems for transporting spinal injury patients between hospitals are currently in use. One common method is to use a wooden ambulance spineboard. This consists of a plywood board with straps and handholds. Sandbags and pillows are used to stabilize the head, with traction being applied manually. These spineboards have the advantages of being lightweight, readily compatible with transport vehicles, and inexpensive. However, it is very difficult to maintain constant traction manually during transportation, and the boards have no padding. Two other systems use portable beds (e.g., Stryker frames). The first uses pulleys and hanging weights, much like the traction apparatus' used on stationary beds. The second (primarily in military use) is called the Collins Apparatus, and uses elastic bungee cords. A study at the NASA-Ames Research Center investigated the force inaccuracy and motion sensitivity of both the weight and Collins traction during ambulance and helicopter transport, and recommended development of methods based on springs [3].

For transport within hospitals patients are commonly transported on the portable traction beds described above.

Finally, the need for traction systems which are compatible with radiographic techniques and hyperbaric treatment has been recognized [2,4,5]. These systems are generally improvised on an individual basis, though some come into common use.

SOLUTION - DESCRIPTION OF STRETCHER

The board for the prototype was constructed of fiberglass over a styrofoam core (fig. 1). This construction was chosen as being relatively radiolucent, strong, lightweight, durable, and easily cleaned. The top surface of the board is slightly concave to better conform to the patient's back and increase patient stability. The bottom surface is contoured to rest securely in the GE model 8800 CT scanner and the Sechrist monoplace hyperbaric chamber. The board has 5 handholds along each side. The grips are comfortable, and have clearance from the ground so that the STS can be picked up easily.

A small spring traction unit was designed and installed (fig. 2). Forces of 5, 10, 15, 20 and 25 lbs. can be generated by selecting combinations of the 3 springs. Because springs were used, the traction force does not vary when the STS is moved or tilted. The angle of traction can be adjusted over about 30 degrees in the anterior-posterior plane.

For padding a 1-inch layer of slow-memory foam (temper foam) over a 1/4-inch layer of closed cell ensolite foam was used. The slow-memory foam conforms to body contours through visco-elastic compliance, and the closed cell foam prevents "bottoming out". Both are highly radiolucent.

The pad is covered with washable and durable vinyl. The patient is secured with straps across the legs, waist, chest, and shoulders. Alternative designs for head restraint systems are currently being considered.

EVALUATION OF PROTOTYPE

The prototype was subjected to testing, which revealed several potential problems. The STS was tested in the GE model 8800 CT scanner. It fit the scanner well, but created "herringbone" artifacts in the image. Similarly, the fiberglass cloth texture was faintly visible in conventional x-rays. These problems are due to excessive x-ray absorption by the fiberglass, and non-uniformities due to hand lay-up of the board.

By substituting carbon fiber for fiberglass, and using production quality lay-up methods, the artifacts can be eliminated [6]. Also, since the styrofoam may not have sufficient strength or rigidity under pressure, it may be replaced with either acrylic foam or a hollow interior vented to allow pressure equalization. A carbon fiber board may also be somewhat lighter in weight than the fiberglass board. Wood is also being considered as a material for the board.

Several other problems have also become apparent: Adjustment of the traction angle is tricky due to the unit's geometry; The traction vector may be slightly off-center laterally, due to the 1-inch separation between the traction cables; the board is difficult to hold from the ends because the handholds are only along the sides; the velcro strap attachments are not ideal for adjustments ; the vinyl pad cover is too radio-opaque (probably due to chlorine content); and the materials for the pad must be reevaluated for fire retardancy and conductivity.

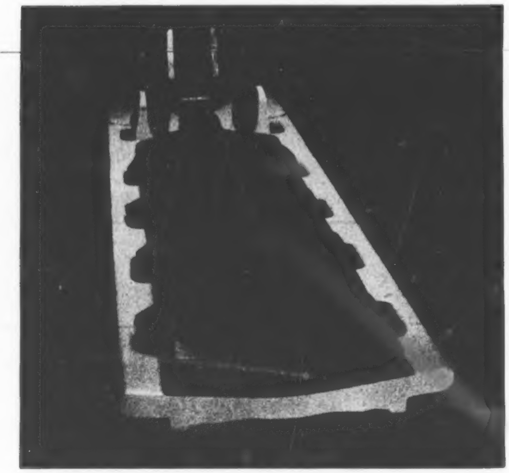


FIGURE 1. Stabilization Transport System. 75 inches long, 21 inches wide, 28 lbs.

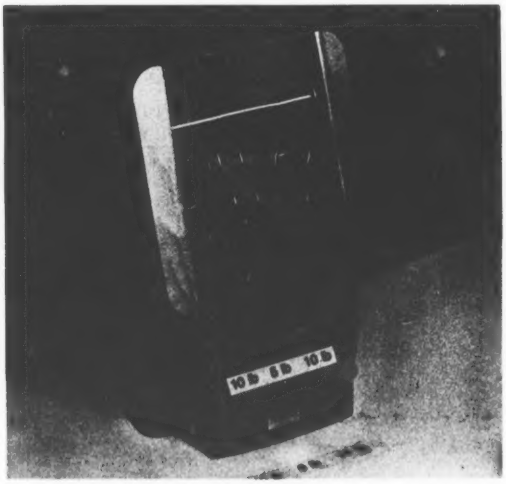


FIGURE 2. Spring traction unit.

CONCLUSIONS

While the STS prototype was successful in many respects, testing has suggested design improvements including:

- A board constructed with a carbon fiber composite skin over acrylic foam. Wood may also be feasible. Handholds in at the ends of the board and mounts for I.V. poles should be added.

- A traction unit with simplified angle-adjustment mechanism. The 5/10/10 lb. springs should be replaced with 4/8/16 lb. springs to give a wider range of forces and finer increments of adjustment. The three traction cables should be as close together as possible to minimize lateral pull.

- Quick-release plastic buckles should be used with the velcro to allow more convenient tightening.

In addition to these changes the STS shape should be modified to be compatible with other CT scanners and hyperbaric chambers, and the head restraint design must be completed. With this work, the STS will be a valuable tool for reducing the risk of cord trauma to cervical spine injury patients.

ACKNOWLEDGMENTS

We would like to acknowledge E.E. Sabelman, T.A. Koogle, and R.L. Piziali for the construction of an earlier prototype and groundwork for the STS [7]. We would also like to thank Dr. Glen Reynolds and Erwin Sprengle of Santa Calara Valley Medical Center, and the Ralph K. Davies Hospital for their ideas and their assistance with the project.

This work was supported by the Palo Alto Rehabilitation Research and Development Center of the Veterans Administration.

REFERENCES

[1] Data obtained through survey of 4 physicians with experience applying cervical spine traction.

[2] We have recently learned of a similar device, designed by Micheal Sukoff at the Western Medical Center, Santa Ana, California.

[3] Connolly, J.P. (March 1980) "Evaluation of mobile traction units used in the transport of the spinal injured" Unpublished report

[4] Reger, S.I. et al. (1981) "A traction plinth for continuous application in thoraco-lumbar fractures" Proceedings of the 4th Annual Conference of the Rehabilitation Engineering Society of North America, Washington D.C. pg 256

[5] Deeb, Z.L. et al. (1978) "A simple traction device for use in the radiology department" Radiology 125:826

[6] Molyneux, M. and Lyons, B.R. (1978) "Carbon fiber reinforced plastics parts in radiological equipment" 33rd Ann. Technical Conf., 1978 Reinforced Plastics/Composites Institute, The Society of the Plastics Industry, INC [7] Sableman, E.E. et al. (1981) "Design of a system for transport of spinal injury patients in traction" Proceedings of the 4th Annual Conference of the Rehabilitation Engineering Society of North America, Washington D.C. pg 259

AUTHOR'S ADDRESSES

Frank Selker
Rehabilitation Research and Development Center
Veterans Administration Medical Center
3801 Miranda Avenue, Palo Alto, CA, 94304

Dr. Conal Wilmot,
Chairman, Department of Rehabilitation Medicine
Santa Clara Valley Medical Center
751 S. Bascom Av.
San Jose, CA 95128

TIBIAL LENGTHENING DEVICE AND TECHNIQUE BASED ON BIOMECHANICAL CONSIDERATIONS

13.6P

S.M. Rezaian, M.D.,F.R.C.S.   D.N. Ghista, Ph.D.
Chedoke-McMaster Hospitals and McMaster University
1200 Main Street West
Hamilton, Ontario L8N 3Z5 Canada

BACKGROUND AND SCOPE

In the management of leg discrepancy, it is more rational to lengthen the short limb (for obvious reasons) than to shorten the longer one. The average orthopaedic surgeon, because of the difficulties of the leg lengthening technique, which sometimes requires multiple operations and long hospitalization, prefers to attack the longer limb by performing epiphyseal stapling, epiphysiodesis or excisional osteotomy.

In order to establish a biomechanically sound technique of leg lengthening, that is simple to surgically implement, a sound external apparatus is first needed to produce secure stabilization of the bone fragments and prevent relative movement between the fractured fragments to induce bone regeneration. Secondly, a meticulous technique of leg lengthening, which does not cause damage to the osteogenesis elements, is required to promote acceleration of bone healing. Obviously the procedure must be free of discomfort to the patient, must be economical and require minimal hospitalization.

A new, safe and very simple technique is presented here in such a way that every orthopaedic surgeon can be encouraged to perform lengthening of the short limb (regardless of its etiology) rather than shortening of the longer one, whenever it is indicated. This leg lenthening technique entails closed osteotomy of the tibia (without concommitant fibula osteotomy), stabilization of the bone segments by our operationally simple Bilateral External Fixator, and gradual lengthening of the osteotomized tibia by carrying out distraction with the aid of the fixator.

This technique is based on safe stabilization of fractured bone segments provided by our simple-to-operate, bilateral External Fixator. The technique entails gradual lengthening of the closed osteomized tibia, with stimulation of the growth plate of fibula. Neither osteotomy of the fibula, nor bone graft with a second operation are required. Hospitalization is shortened to just 3-6 days. Daily lengthening is carried out as out-patient or home procedure, while the patient is attending his daily education or vocation.

A below knee cast is applied when the lengthening is completed (4-6 weeks after the operations). The pins are removed through window openings on the cast, when good callus is visible on the x-ray picture (9-10 weeks after operation). The cast is discarded when the medublary canal is reformed in the lengthened section on roentgenography (5-7 months after operation).

THE BILATERAL EXTERNAL EXTENSOR-FIXATOR

Our external extension device (Fig. 1) whose Mark 1 version is made by OEC Orthopaedic Group, U.K., consists of two longitudinal bars, which are placed laterally on either side of the to-be-lengthened bone. Each bar has two jigs connected by a central turnbuckle; the jigs of the bar, which is to be placed laterally, have threaded holes.

These bars securely stabilize the osteotomized bone fragments by means of 5 to 6 pins which have sharpened distal ends to facilitate self-drilling into the bone fragments, and are threaded in their middle sections in order to secure a firm grip in the bone. The threaded holes in the proximal and distal jigs of the lateral bar also enable the pins to be guided, through the bone fragments parallel to one another, into the corresponding holes in the jigs of the medial bar.

The two turnbuckles in the middle sections of the bars enable adjustment of the apparatus for different anatomical sizes and permit gradual and uniform distraction of the bone for leg lengthening. Two pairs of locking nuts fix the apparatus rigidly in the desirable configuration in such a way that the two osteomized sections of the tibia and the apparatus function as a single hybrid structure.

Our Mark-2 version of this apparatus has a provision to monitor and regulate the amount of distraction. We would also like to emphasize that the bilateral application of our device enables us to apply uniform distraction and extension strain across the osteotomized section. Also, during weight bearing, it provides greater stability and stiffness to the osteotomized limb skeleton, prevents the development of tensile strains at any point of the fractured interface (due to ground reaction induced bending moment), and thereby promotes more uniform bone remodelling over the tibial cross-section.

LEG LENGTHENING TECHNIQUE

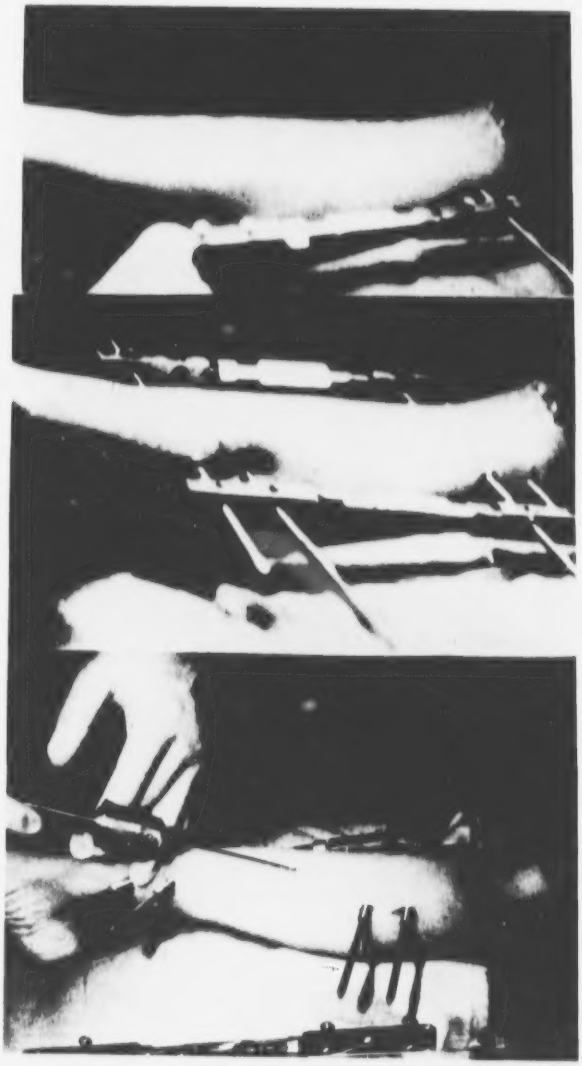
Under general anaesthesia and surgical conditions, but without the use of tourniquet, the lateral bar of the apparatus is held against the lateral side of the leg of the patient; while the ankle joint is held in maximum dorsi-flexion, a special self-drilling pin or power drill is inserted through the most distal hole of the lateral bar, then through the fibula and through the tibia (just 1-2 cm above their distal epiphyseal plate), to emerge on the medial side of the leg and enter the corresponding hole in the medial bar (fig. 2a). In order to accomplish this task, the pin must be passed about 5° postero-lateral to anterior-medial in the leg, because the fibula is slightly posterior to tibia. This pin stabilizes the ankle joint and holds the shaft of the fibula to the tibia. This pin stabilizes the ankle joint and holds the shaft of the fibula to the tibia. Then the most proximal pin and the middle two pins are similarly passed from the lateral bar, but only through the tibia, into the medial bar, as shown in fig. 2b.

Thereafter the two lateral bars are removed. A small 1-2 cm incision is made in the middle section of the medial side of the tibia, using a 3/64 inch drill bit. Multiple holes are made in different planes to weaken the shaft of tibia. At this stage, the shaft of tibia is broken by a hit of the ulnar border of the hand. Now the bars are reapplied. The grab screws and nuts as well as the turnbuckle are tightened to stabilize the bone segments. This stage is illustrated in fig. 2c. Osteotomy of the fibula is not carried out for the purpose of lengthening. The shaft of the fibula is stabilized by means of the most distal pin, with respect to the tibial shaft, while the proximal epiphysis is held in place by the strong conjoint ligaments of the biceps femoris and the collateral ligaments of the knee joint. By regulated rotation of the turnbuckle, the tibia is now gradually lengthened at the site of the closed osteotomy. The fibula is made to proportionately gain in length by the gradual distraction of the upper epiphyseal plate (fig. 2d).

POST-OPERATIVE MANAGEMENT

The patient can be ambulated on crutches 1-2 days after the operation (Fig. 3a) and can be discharged 3-5 days after operation. The patient will be instructed each day to sit down, flex his knee and release the nuts, turn the turnbuckles for only half a revolution (or 1¼ mm: see Fig. 3b). Thus within 32 days, 4 cm length can be gained. An analgesic drug is seldom required for leg lengthening.

When the desirable length is achieved, a full-weight bearing cast (well molded around the pins) is applied (fig. 3c). When a good callus is visible, an x-ray is taken through the cast (fig. 3a). The pins are removed, under general anaesthesia, through a window on the cast. It takes 6-8 weeks for the medullary cavity to be visible in the lengthened area and for the cortex to be well molded.



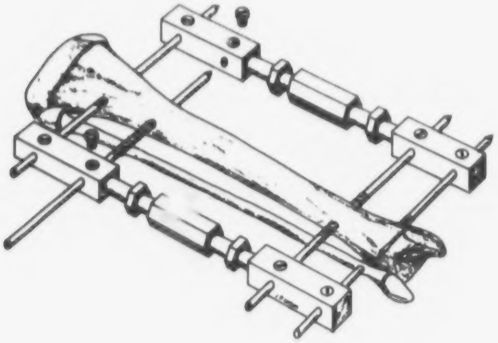


Fig. 1: The External Fixator for leg lengthening, showing lateral bars with turnbuckles, and threaded pins (with only the most distal pin passing through both the tibia and the fibula).

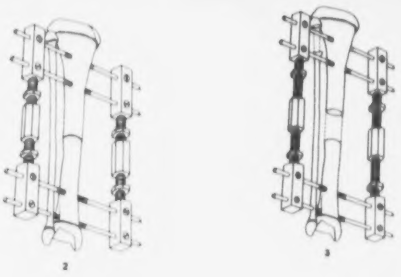


Fig. 2: Steps of lengthening, showing (a) stabilization of the ankle joint, (b) the fixator in place, (c) preparation of the tibia for osteotomy, (d) tibial osteotomy and distraction.

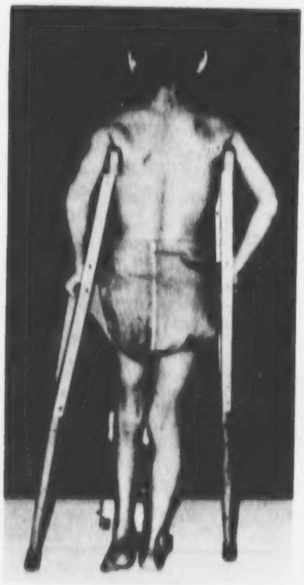


Fig. 3(a-b): Post-operative management: ambulation on crutches, self-distraction by turning fixator turnbuckles.

Fig. 4a

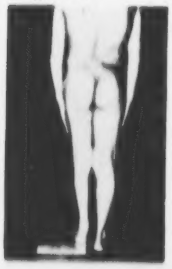
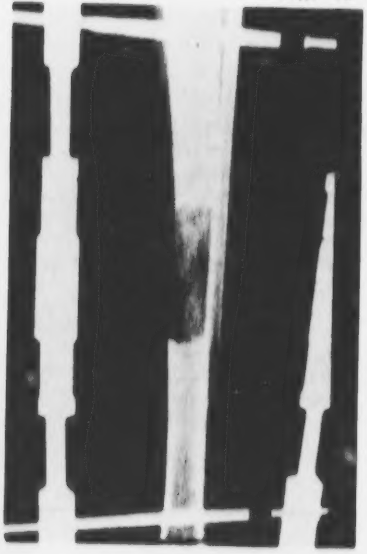


Fig. 4b



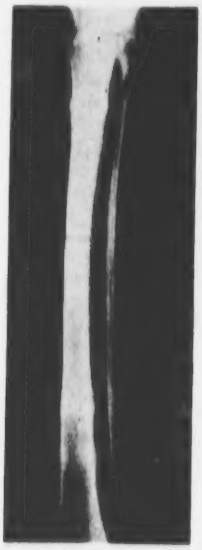


Fig. 4c

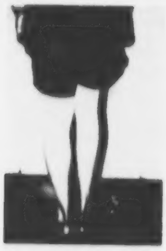


Fig. 4d

Fig. 3(c-d): Post-operative management, with cast application, and checking for callus formation before fixator removal.

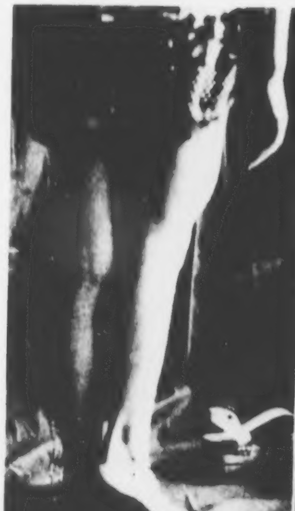


Fig. 5a

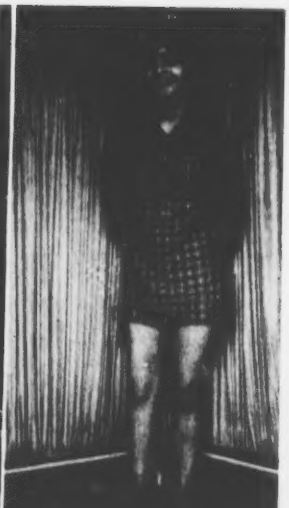


Fig. 5b

SAMPLE CASE PRESENTATIONS

Case 1

Fig. 4a shows a polio patient (boy, age 9) with a 6 cm shortened left leg. Figs. 4b and 4c show x ray pictures 42 days and 165 days after the operation. Fig. 4d shows the outcome after surgery.

Case 2

Fig. 5a shows a girl aged 9 with congenital deformity of the right leg. Fig. 5b shows the outcome of the surgery.

DETERMINATION OF KNEE MOTION FOR EXTERNAL LINKAGE DESIGN

Peter S. Walker, Ph.D., Hisashi Kurosawa, M.D., and Ashima Garg.
Orthopedic Biomechanics Laboratory, Brigham & Women's Hospital, Boston, and
Clinical Bioengineering Laboratory, V.A. Medical Center, West Roxbury;
Affiliated with Harvard Medical School; and Department of Orthopedic Surgery,
University of Tokyo

ABSTRACT. External knee linkages are used mostly in orthotic devices to provide stability and to limit flexion, in cases of ligamentous injury, general instability, or muscle weakness. The hinge-distractors where the linkage is attached rigidly to the bones by transcutaneous pins, are used following surgery for acute injury or for gradually releasing fibrous ankylosis. To be most effective in guiding knee motion, avoiding abnormal ligamentous elongations and minimising skin-orthotic movements, the knee linkage should closely follow the motion of the knee in its normal condition. The linkages available today, do not achieve this because they do not account for the differences of motion between the lateral and medial sides of the joint.

This paper reports a method for describing and measuring knee motion, particularly applicable to external linkage design. The motion of the femur was described relative to the fixed tibia. The posterior femoral condyles were shown to be accurately modelled as spherical surfaces. This enabled the centers of the medial and lateral spheres to be determined from a set of sagittal plane radiographs at different flexion angles. The transverse axis of the femur through the centers of the spheres, determined as a function of flexion angle. The angles of internal-external rotation, varus-valgus rotation, and anterior-posterior translation were also determined.

The extensions of the transverse femoral axis medially and laterally showed the motions which need to be imparted to the femur by an external linkage. The lateral side moved steadily backwards while the medial side moves steadily forwards during flexion. This data is the starting point for designs for an external knee linkage. Preliminary designs will be shown.

INTRODUCTION.

There are many available designs of external knee linkage, for incorporation into knee braces. Many of the linkages are fixed pivot metallic hinges, the discrepancy in pivot motion to actual motion being taken up by brace-to-tissue slippage and by soft tissue deformations. 'Polycentric' motion has been achieved in several ways, such as by a double-axis pivot joint, the first being by Loth in 1921. The first polycentric linkage which allowed transverse rotation was by Taylor in 1975 while the first guided linkage was by Helfet in 1980. One of the most recent polycentric planar motion devices, the 'Genucentric' was described by Foster & Milani (1981). The hinge-distractor described by Volkov and Oganesian (1975) used a rack-and-pinion on each side of the joint, again achieving polycentric but planar motion.

If general enhancement of stability is needed, present linkages are reasonable, but often produce skin discomfort. If however protection of sprained ruptured or repaired soft tissues (e.g., ligaments) is required, the linkages are not satisfactory. Even small changes in the imposed center of rotation can cause large proportionate changes in ligaments lengths.

Our approach to designing an accurate linkage is to determine the actual knee motion with reference to readily identified bony landmarks. The first stage is the identification of these landmarks, and the second stage is to measure average knee motion and the variations.

BACKGROUND - KNEE MOTION

The motion of the knee during flexion-extension involves rolling and sliding of the femoral condyles on the tibial plateaus. Many attempts have been made to describe the motion, ranging from anatomical observation to complex three-dimensional analyses. Important underlying questions are whether or not there is a unique path of motion, and what are the differences in motion between different knees. For the unloaded joint, the considerable laxity in anterior-posterior motion and in internal-external rotation, suggests that there is no unique path. However, if a compressive force is applied, the laxity decreases and the stiffness increases meaning that relatively large forces or torques are needed to move the joint from its neutral position (5,8). Hence, under conditions of compressive loading, a unique path is likely.

Several motion analyses have used Rouleaux's method to determine the paths of the instant centers of rotation, assuming planar flexion-extension motion and ignoring motion in other planes (13). The method has been extended to account for the rotation which is known to occur about the tibial axis, by determining the instant centers of the medial and lateral condyles separately (1). The transverse lines joining the points were considered to be the 'instant axes' and shown very clearly in a model. These axes were closely parallel in the frontal plane but showed transverse rotation when viewed superiorly. However the inaccuracy of determining three dimensional motion from a two dimensional instant center study, has been pointed out (10).

There is still disagreement as to whether the transverse rotation about the tibial axis occurs primarily towards extension, the 'screw-home mechanism', or throughout flexion. (3,12).

Recognizing the 6 degrees of freedom of the knee, rigorous methods have been applied to describe these in a unified form including the screw axis (6,7). Three independent rotations were computed and 'orthopedic angles' used to describe the group of Euler angles used (2). The methods were experimentally and analytically complex however, involving the implantation of three small beads in the femur and tibia and taking biplanar radiographs, and in arranging for a six degree of freedom linkage rigidly connecting the femur and the tibia.

Our objectives were to devise a method whereby knee motion under load-bearing could be simply yet accurately described for the living subject and to determine the motion for knee specimens and living subjects as a data base.

MATERIALS & METHODS

Geometrical Measurements

An easily identifiable femoral reference axis was the center of the shaft seen in the saggital view. A transverse axis is more difficult to define. However preliminary observation suggested that the posterior femoral condyles were closely spherical affording the opportunity to define an axis through the sphere centers. The sagittal radii around the posterior condyles of 14 fresh normal specimens were measured using templates at 1 mm increments. In the anterior view, measurements of the width between the lowest points on the condyles and the radii of the arcs were measured at locations corresponding to 0, 30, 60, 90 and 120 degrees of flexion. Sagittal plane radiographs were taken of all joints. Points on the medial and lateral posterior condyle outlines were digitized, and a computer program determined the radii. In order to correlate the gage measurements with those from the computer, the thickness of the cartilage was measured.

Twenty additional normal distal femurs were mounted in blocks and cut in 16 equal sagittal slices. The sections were digitized into a computer. The coordinates were corrected to a standard femoral condyle width of 80 mm. A computer program was written to determine the accuracy of the optimum spherical surfaces which could be matched to the posterior femoral condyles, (9), in an arc corresponding to 15^{0} to 105^{0} of flexion. A simple optimisation procedure was used. The graphical output displayed all sections in the sagittal and frontal planes together with the average spheres.

Kinematic Measurements

Fourteen fresh normal cadaveric knees were cut 20 cm above and below the joint and the muscles removed, but the patella tendon, patella, ligaments and capsule were preserved. A test rig was constructed (11) in which the tibia was fixed and a load applied to the quadriceps tendon just above the aptella (Fig.1). Different flexion angles were obtained by adjustment of the quadriceps length. Lateral radiographs were taken at 15 degree intervals from zero to 120 degrees of flexion.

To obtain data from normal knees in load-bearing, video radiographic tapes were taken from 8 normal males aged 23 to 41 years in ascending and descending a high step. To maintain the tibia fixed a special knee support was used. Photographs were taken at 15 degree intervals to produce a similar set of views to those from the cadaveric specimens.

Analysis of Radiographs

Axes were defined in the tibia relative to a line joining the anterior and posterior corners of the medial articulating surface (Fig.2).

Each set of radiographs was analyzed by inputting points from a digitizer to a computer. A computer program determined the best fit radii and center of the circle through each periphery. All dimensions were then standardized to an a-p length of the medial tibial condyle of 50 mm, while the m-l spacing between the centers of the spheres of the femoral condyles was standardized to 44 mm. Also recorded was the distance from the posterior point P on the lateral tibial condyle to the origin. The computer calculated the angle of transverse rotation (R), the varus-valgus angle (V), and the x,y coordinates of the cneters of the medial and lateral 'spheres' (Fig.3). The 3 angles can be considered as independent Eulerian angles (3), while the displacements in two dimensions of each spherical center was recorded, rather than the displacements of the origin itself. We did not attempt to measure the z coordinates of points M & L.

RESULTS

Geometrical

In either the sagittal or frontal planes one particular radius gauge usually gave a close fit around the entire arc. The thickness of the articular cartilage averaged 1.5 mm with ±0.5 mm variations. The radii were determined from the radiographs for each knee from all sagittal views at the different flexion angles - this corresponded to femoral profiles at different values of internal-external rotation. The standard deviations for these different angles was only about 3% of the mean, indicating a profile independent of internal-external rotation angle, consistent with spherical surfaces. The results are shown in Table 1. Comparing the mean values of the radii determined by the computer (bone outline) and by direct measurement (cartilage outline) and allowing 1.5 mm of cartilage, there was good agreement for all knees, the mean difference being 1.6 mm. Comparing the averages of the radiographic and measured results, there was accurate agreement, with an average radius of curvature of 20 mm for the 'standard knee'.

The radii in the frontal plane were consistent around the curve of the posterior condyles (Table 2). On average, the medial radius was slightly larger than the lateral, at 21.0 mm and 18.6 mm respectively. These values are close to the sagittal radii, consistent with spherical surfaces. The spacing between the lowest points on the femoral condyles were constant in the 0-120 degree range, the largest deviations from the mean being only 2 mm. The average spacing was 45.9 mm.

As of this writing, the digitized sections input to the computer have not been fully analyzed. However, a graphical result from one particular knee is shown in Fig.4. In the sagittal view, the circles closely match the maximum medial and lateral peripheries. In the frontal view, the circles match closely, but different angular profiles would be needed to gain an overall impression. In this example, the mean error from the calculated spheres was about 1 mm with a standard deviation of only 0.2 mm. With better optimisation, an even closer fit could be obtained.

Taking all of the data, the posterior femoral condyles can be accurately modelled by parts of spheres, of radius 20 mm and with the centers spaced apart by 46 mm. The line joining the centers of the spheres can now be regarded as the 'axis of the femur' and the motion of this axis relative to the tibia used to describe the motion of the knee.

Motion of Cadaveric Knees

From 0-120 degrees of flexion, the medial center moved forwards by 4.5 mm to mid range and then backwards 2.3 mm (Fig.5). The lateral center moved backwards a total of 17 mm. In the y-direction, the lateral center moved only 1 mm throughout the entire range, the medial center being similar from 30-120 degrees of flexion. However, the medial center moved downwards by three millimeters from 0-30 degrees, probably due to sinking lower into the tibial surface.

There was a steady external rotation of the femoral axis on the tibia with flexion, reaching 20.2 degrees. This roation is consistent with the translational movements of the medial and lateral centers. There was a decreasing rate of external femoral rotation with flexion, especially after 75 degrees of flexion.

From 0-45 degrees of flexion, there was a progressive varus movement of the femoral axis up to 4.2 degrees and thereafter a slow decrease to 2.2 degrees.

Motion of Knees of Volunteers

The motion patterns, the absolute values, and the standard deviations, were virtually identical to those from the specimens. Using the t-test for the means of uncorrelated samples, there was no statistical difference ($p<.01$) between the two groups. The medial center moved anteriorly by 4.4 (±2.7 S.D.) millimeters from 0-45 degrees of flexion, and then moved backwards to a final distance of 0.3 mm. The lateral center moved steadily posteriorly to 14.1±6.7 millimeters at 120° of flexion. The transverse rotation reached 16.9±6.0 degrees at 120° of flexion.

The motion of the femoral axis join the lateral and medial spheres with respect to the tibia is shown in Fig.6. The particular view shown was obtained by carrying out rotational and viewing transformations in the computer. The femoral axis is projected medially and laterally for better visualization. The pivot point of the femoral axis lies between the medial and lateral centers, but only a few mms from themedial center. The net movement of the medial center is slightly anterior which is substantially magnified when the axes are projected. Similarly, the net posterior movement of the lateral center is magnified.

DISCUSSION

A significant finding was that the posterior femoral condyles can be closely modelled as spherical surfaces. Using this fact, the centers of the lateral and medial spheres can be readily determined from sagittal plane radiographs, and used to define a transverse axis in the femur. The longitudinal axis is readily determined parallel to the bone shaft. Errors in determining the sphere centers are: the lack of true sphericity, distortions in the radiographic views, digitizing errors, and lack of constancy of the tibial profile in testing living subjects. The complete error analysis is beyond the scope of this paper, but is calculated at most ±1.5 mm.

An advantage of the method was that it was simple to obtain the data and to analyze the radiographs, both on specimens and on normal volunteers. Although we used a computer, the entire procedure could be carried out using templates to determine the condylar centers. Only one anterior-posterior x-ray is needed, to determine the distance between the lateral and medial sphere centers. Taking account of the actual knee motion, particularly the fact that the medial side moves forwards and the lateral side backwards during flexion, is necessary for the design of external orthoses and prostheses, and to linkages for external fixation devices.

CONCLUSIONS

1. The posterior femoral condyles were shown to be accurately modelled by spherical surfaces.
2. The line joining the centers of these spheres, determined from sagittal plane radiographs, was called 'the transverse femoral axis'.
3. The lateral side of the femur moved backwards and the medial side moved forwards during flexion.
4. This data is necessary to design an accurate external knee linkage.

TABLE 1

Sagittal Bone Outline Determined by Computer from Radiographs. 14 bones at 9 flexion angles 0 - 120°

MEAN MEDIAL RADIUS 18.1 + 1.5 cart. = 19.6 mm
MEAN MEDIAL S.D. 0.5 mm
MEAN LATERAL RADIUS 19.3 + 1.5 cart. = 20.8 mm
MEAN LATERAL S.D. 0.7 mm
Sagittal Cart. Outline by Direct Measurement.
MEAN MEDIAL RADIUS 19.9 mm
MEAN LATERAL RADIUS 20.4 mm

TABLE 2

Frontal Cartilage Outline Determined by Direct Measurement

	0°	30°	60°	90°
Med.	21.4	20.9	20.7	20.9mm (av.21.0)
Lat.	19.1	18.6	18.8	17.8mm (av.18.6)

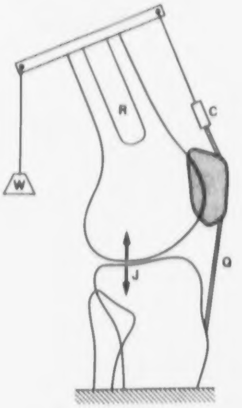


FIG 1

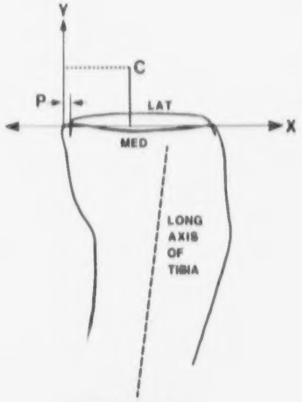

Y
C
P
LAT
X
MED
LONG AXIS OF TIBIA

FIG 2

ACKNOWLEDGEMENTS

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REFERENCES

1. Blackarski, P.A., Somerset, J.H., and Murray D.G.: J. Biomech. 8:375, 1975.
2. Chao, E.Y.S.: J. Biomech. 13:989, 1980.
3. Hallen, L.G., and Lindahl, O.: Acta. Orthop. Scand. 37:97, 1966.
4. Harding, M.L., Harding, L., and Goodfellow, J.W.: J. Biomech. 10:517, 1977.
5. Hsieh, H-H, and Walker, P.S.: J. Bone & J. Surg. 58A:87, 1976.
6. Kinael, G.L., Hall, A.S., and Hillberry, B.M.: J. Biomech. 5:93, 1972.
7. Lewis, J.L., and Lew, W.D.: J. Biomech. 10:675, 1977.
8. Markolf, K.L., Bargar, W.L., Shoemaker, S.C., and Amstutz, H.C.: J. Bone Jt. Surg. 63A:570, 1981
9. Rogers, D.F., and Adams, J.A.: Computer Graphics, McGraw Hill, 1976.
10. Soudan, K., van Audekercke, R., and Martens, M.: J. Biomech. 12:27, 1979.
11. Volkov, M.V., and Oganesian, O.V.: J. Bone Jt. Surg. 57A:591, 1975.
12. Trent, P.S., Walker, P.S., and Wolf, B.: Clin.Orthop. 117:263, 1976.
13. Walker, P.S., Shoji, H., and Erkman, M.J.: Clin.Orthop. 89:160, 1972.
14. Wang, C-J, and Walker, P.S.: J. Bone Jt. Surg. 56A:161, 1974.

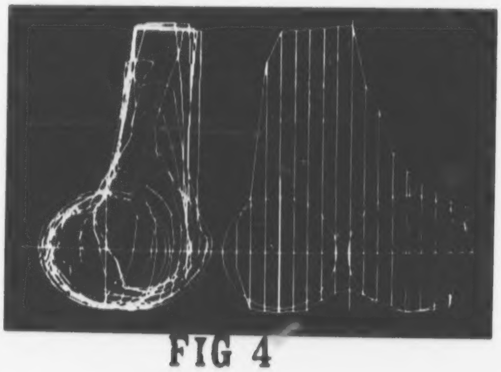


FIG 4

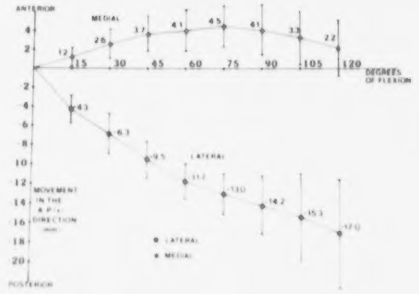


FIG 5

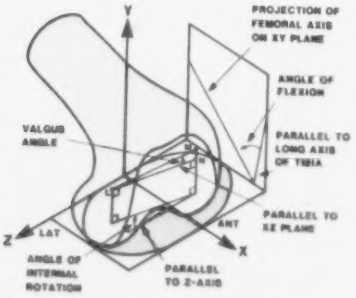

Y
PROJECTION OF FEMORAL AXIS ON XY PLANE
ANGLE OF FLEXION
VALGUS ANGLE
PARALLEL TO LONG AXIS OF TIBIA
PARALLEL TO XZ PLANE
ANT
Z
LAT
X
ANGLE OF INTERNAL ROTATION
PARALLEL TO Z-AXIS

FIG 3

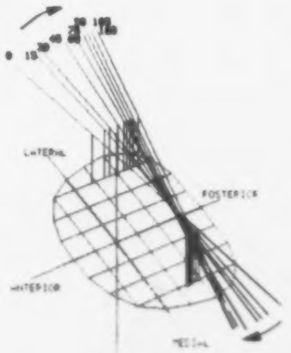

0
15
30
45
LATERAL
POSTERIOR
ANTERIOR
MEDIAL

FIG 6

14.1

RECREATIONAL APPLICATIONS OF A ROBOTIC AID

Barbara Angius, K.G. Engelhardt, Larry J. Leifer

Palo Alto Veterans Administration Medical Center
Rehabilitative Research and Development Center

ABSTRACT

One of the primary needs of the disabled is the need for recreation. Medical Robotics is an emerging field in which advanced technology is being developed to benefit the severely disabled. This paper discusses a set of programmable tasks using a robotic aid for recreational applications. A group of 5 high-level quadriplegics, living in a congregate setting will define recreational tasks for the robot and provide feedback to designers and developers. An interactive evaluation model will be used to assess the integration of system, task, and user (Figure 1).

INTRODUCTION

Spinal cord injured patients begin a new lifelong learning process at the moment of their injury. This rehabilitation process requires retraining in self-care, vocational preparation, and lifestyle adjustment. Advanced assistive devices are applicable to this process. The primary function of a voice-controlled robotic aid is to use state-of-the-art technology to give patients increased control and independence over their environments and to restore as many manipulative functions as possible.

Recreational tasks provide a challenging and motivating way to redevelop skills and provide leisure activities for the disabled person. Devising creative robotic applications for recreation will be among the major objectives in the future research and evaluation of a robotic manipulator for the severely disabled.

BACKROUND

Robotics

The evolution of rehabilitative robotics began in the early 60's with the Case Institute of Technology's computerized orthosis (1). In the early 70's, the University of Heidelberg developed an industrial manipulator and minicomputer to store points and to integrate special purpose devices (telephone, typewriter, custom mouth-stick controlled keyboard) primarily for vocational use (2). Johns Hopkins University's Applied Physics Laboratory designed a more advanced robotic system, permitting preprogrammed manipulation sequences for standard ADL tasks, such as book retrieval and food service (3). The French Spartacus Robotic Aid made other contributions to the evolution of robotics. This rehabilitative system implemented new input modes, and was the first robotic aid with optical proximity detectors for grasp and and object localization (4).

"The Stanford University and Palo Alto VAMC Robotic Aid is the most recent attempt to demonstrate the feasibility of using robotic technology to satisfy the manipulative needs of the severely disabled" (5). This aid (Figure 2), a Unimation Puma 250 arm and controller driven by a Z-80 based microcomputer, has the capacity for voice, keyboard, head motion, and joystick inputs, synthesized voice output, and optical proximit sensors for advanced sensory capacity. The Stanford Robotic Aid is low in learning difficulty an flexible in training approach (6). The previou research in robotics illustrates a lack of application and evaluation of recreational uses of th manipulators.

User-specific training with the robotic ai is in progress at the Palo Alto VA Rehabilitatio Research and Development Center. This trainin focuses on ADL tasks such as food preparation appliance and telephone use.

Recreation for the Disabled

"There is hardly any sport in which person with disabilities do not take part, nor an disability for which there are no specia organized games or olympiads" (7). Variou organizations cater to the outdoor recreationa needs of the disabled. Equipment adapted to th special needs of the disabled such as recreationa wheelchairs, boating equipment, surfboards, ski- sleds, and other recreational devices ar available (8). Injury level could be a factor i use of some equipment by the severely disabled Adaptive indoor recreation is just as important a outdoor recreation, yet organizational support o this need is not apparent.

Robotic Recreationational Aids

There have been a few efforts to adap robotics to recreation for the hobbyist. Th BORIS home chess computer comes equipped with it own robot arm attached to a chessboard, allowin the computer to carry out its own moves an captures. The HOBBY ROBOT serves a simila function. It has a two-axis arm with magnet lifter and pen holder for plotting and drawing ARMATRON, a toy robot manipulator manufactured b the Tomy Corporation, challenges one's skill an coordination. Through joystick control, the use can pick up and move light objects. It is ou hypothesis that the above recreationa applications of robotics can be adapted for use b the disabled.

METHODS AND MATERIALS

The methodology proposed for the integratio of a system, task and user with recreation wil implement the evaluation model developed b Engelhardt, et al. (9). This model was devised a a tool to facilitate a flexible, ongoin evaluation process. Its objective is to provid user feedback to the developers of advance assistive devices. This objective will be met i the evaluation of recreational tasks b introducing the robotic aid into a congregat living environment which houses fiv quadriplegics. They will be asked to perfor specific recreational tasks and will then be aske to design some of their own. Their performanc will be filmed. This film will serve a documentation of their learning process and will provide a foundation for continued research. By evaluating recreational tasks, fundamental human factors information on training procedures, performance variables, needs, applications, acceptance, preference and other psychosocial issues will be compiled.

The specific recreational tasks targeted for user application and evaluation are:

1. Robotic control of a board game. This task has been suggested by patients as a recreational and leisure time activity. The system could be preprogrammed for the specific positions on a chess, backgammon or checker board and the game could be played using voice or joystick control (Figure 3). These games are challenging and thought provoking.
2. Painting with the robotic arm. Creative expression is essential to a well-balanced life-style; severely disabled people who have lost the functioning of their hands are robbed of this expression. By guiding a paintbrush grasped by the robot the user could control the arm motions and brush strokes to create unique art work.
3. Dance choreography. Visual designers have applied the movements of a robotic arm to musical pieces and have produced film footage of the finished version (10). This is a highly esthetic endeavor for a severely disabled individual, and present technology allows for the development of such a visually appealing creative application.
4. Robotic control of videogames. Videogames are becoming highly popular in America. Implementation of this technology for the disabled will provide a pleasureable and visually stimulating pastime. Furthermore, learning paradigms and control techniques can be clinically evaluated.

There are many other options for recreational uses of a robotic aid. The above are the major tasks that have been developed for training and evaluation procedures.

DISCUSSION

"The rehabilitation process of spinal cord injured patients must incorporate a broad spectrum of short term and long term goals. The numerous technological advances of the last 2 decades afford new potential for addressing the needs of the spinal cord injured person" (11). Applying medical robotics to serve the disabled community can only help to achieve these goals. The technology available in the Stanford/VA project, because of the degree of interactiveness, is the most user-specific developmental system to date. With advances in robotic technology, recreational innovations become more realistic for the disabled person and offer increased potential for creativity in independent living.

Complementary to technological developments, evaluation research efforts are essential in facilitating the interactive information flow from user to designer. The model, created at the RR&D Center for task evaluation, calls for simultaneous investigation of both the machines's and human's performance. It is hypothesized that this focus will help determine desirable characteristics for both the user and the system. This model will allow us to critically evaluate recreational tasks using the robotic aid.

CONCLUSION

"All of the tasks and activities in a person's life could be categorized into various types of activities. Three very general types of activities shall be called: independent living activites, vocational activities, and recreational activities. The order in which the types of activities have been listed represents the priority on which rehabilitation centers in the U.S. base their activities and programming. Many governmental agencies would place vocational activities at a higher priority than independent living activities. A minority of programs place recreational activities as the highest priority when making programming and funding decisions" (12). This quote by Peter Axelson, a biomedical engineer specializing in recreational devices for the disabled, and disabled himself, outlines the current status of rehabilitative activities in this country. It is evident from this statement, and from the lack of research in robotic recreation, that there is a need for innovations in recreation for the disabled. The coupling of the Interactive Evaluation Model with proposed recreational tasks with a robotic aid will serve as a foundation for recreational research and development for the disabled.

Figure 1

The application of the Interactive Evaluation Model to the development of recreational tasks.

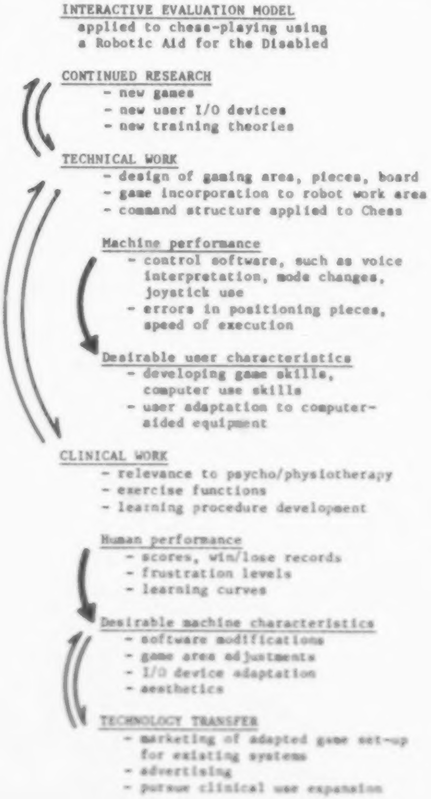

INTERACTIVE EVALUATION MODEL
applied to chess-playing using
a Robotic Aid for the Disabled
CONTINUED RESEARCH
- new games
- new user I/O devices
- new training theories
TECHNICAL WORK
- design of gaming area, pieces, board
- game incorporation to robot work area
- command structure applied to Chess
Machine performance
- control software, such as voice interpretation, mode changes, joystick use
- errors in positioning pieces, speed of execution
Desirable user characteristics
- developing game skills, computer use skills
- user adaptation to computer-aided equipment
CLINICAL WORK
- relevance to psycho/physiotherapy
- exercise functions
- learning procedure development
Human performance
- scores, win/lose records
- frustration levels
- learning curves
Desirable machine characteristics
- software modifications
- game area adjustments
- I/O device adaptation
- aesthetics
TECHNOLOGY TRANSFER
- marketing of adapted game set-up for existing systems
- advertising
- pursue clinical use expansion

Figure 2 The Stanford/VA Robotic Aid.

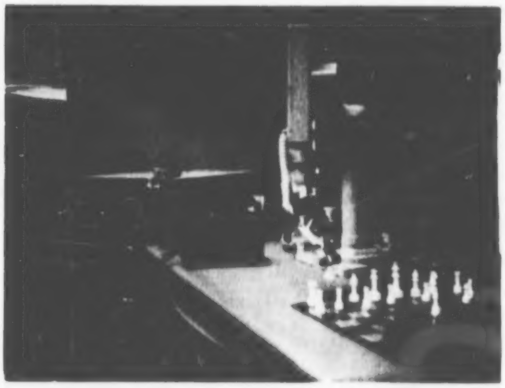
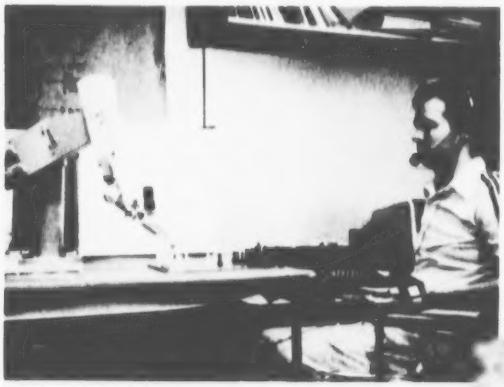


Figure 3
Recreational task using the Robotic Aid.



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Machiel Van der Loos
Mechanical Engineer
Rehabilitation Research and Development Center
Palo Alto Veterans Administration Medical Center

Peter Axelson
Biomedical Engineer
Rehabilitative Research and Development Center
Palo Alto Veterans Administration Medical Center

REFERENCES

(1) Reswick, J., and Mergler, K., Medical Engineering and Progress Report on Case Research Arm Aid, Case Institute of Technology, Report EDC 4-64-3, 1962.

(2) Roesler, H., and Paeslack, V., Medical Manipulators, First CISM-IFToMM Symposium of Theory and Practice of Robots and Manipulators, Udine, 1974, pp. 158-169.

(3) Schneider, W., Schmeisser, G. and Seamone, W., Computer-Aided Robotic Arm/Worktable System for the High Level Quadriplegic, IEEE Computer, January, 1981, pp. 41-47.

(4) Vertut, J., Charles, J., Coiffet, P., and Petit, M., Advance of the New MA23 Force Reflecting Manipulator System, Second CISM-IFToMM Symposium on Theory and Practice of Robots and Manipulators, Warsaw, 1976, pp. 307-322.

(5) Leifer, L., "Rehabilitative Robotics", Robotics Age, May/June, 1981, pp. 4-15.

(6) LeBlanc, M., and Leifer, L., "Environmental Control and Robotic Manipulation Aids", Engineering in Medicine and Biology Magazine, December, 1982, pp. 16-19.

(7) Sports for Disabled Individuals, Rehab. Brief, Vol. IV. No. 3, Jan. 26, 1981.

(8) Enders, S., Technology for Independent Living Resource Guide, Rehabilitation Engineering Society of North America, Houston, Texas, August 20-21, 1982.

(9) Engelhardt, K.G., et al., "Methodology and Preliminary Findings from the Evaluation of an Interactive Manipulation Aid", Proceedings of the Fifth Annual Conference on Rehabilitation Engineering, Houston, Texas, August 22-26, 1982, p. 100.

(10) Sun, R., Ballet for One Arm, Video choreography, Design Div., Dept. of Mechanical Engineering, Stanford University, Spring, 1978.

(11) Engelhardt, K.G., RREALL, Proposal submitted to the Veterans Administration Merit Review Board, February, 1983.

(12) Axelson, P., Attitudes in Designing for Persons With Disabilities, Paper submitted to the 6th Annual Conference on Rehabilitation Engineering, San Diego, April, 1983.

ADDRESS OF AUTHOR

Barbara L. Angius
Rehabilitation RR&D Center
Palo Alto VA Medical Center
Mail Stop 153
3801 Miranda Ave.
Palo Alto, CA 94304.

ADAPTIVE CONTROLLERS FOR VIDEO GAMES AND COMPUTERS

Ken S. Yankelevitz

KY Enterprises

ABSTRACT

This paper discusses an innovative application of technology to facilitate recreation by severely handicapped individuals. Adaptive controllers for video games and computers for use by these people have been developed which replace joysticks. These controlles can be used by people with spinal cord injury, cerebral palsy, muscular dystrophy, amputations and stroke. The controllers interface with the Atari 400/800 computers, Commodore Vic-20 computer, Atari 2600, Sears Telegame, and Colecovision. Adapters are available for the Texas Instruments, Apple, and Radio Shack TRS 80 computers.

INTRODUCTION

Tommy Gonzales, 13, is a video game freak, the kind you hear about who plays for hours in the arcade on a single quarter. Once he was playing the only PacMan machine in his neighborhood for such a long time that a group of older boys got impatient waiting for their turns and threw him into a trash can! That was before a gunshot severed his spinal cord. Tommy is now a C-3 quadriplegic. He is only able to move his head and needs the aid of a respirator to breathe. For seven months he lay in the hospital unable to participate in his favorite activity. With the help of a specially adapted mouth control he's back to playing video games for hours at a time, without assistance. It's one of the very few things he can do for himself. With the mouth operated joystick, he scores over 20,000 on PacMan.

John Carasik is a 12 year old boy with severe cerebral palsy. He is spastic and has almost no control over the muscles in his body. But the ones he does control, he can use to smash electronic space debris with as much pleasure as any youngster his age. His favorite game varies and his scores are always improving. At last count, he had gotten over 30,000 on Missle Command. John has just recently been able to play video games because he's acquired a controller he can use. He plays with a botton controller that he operates with his feet. It is mounted on the footrest of his wheelchair and consists of five large soft-touch button switches. He resets the game with a similar button mounted on the side of his chair.

John is non-vocal and uses a computer to communicate. Most of his conversation consists of a list of the cartridges he wants for his video game. The controller has opened up a whole new world for him. Before he got it, video games were a frustration for him and his mother. She would operate the joystick under his direction, but never seemed to react fast enough. She tried all sorts of methods of strapping the joystick to John's wheelchair and body at various points, trying to find some way for him to be able to operate it himself. Even so, she'd have to be with him to reset the game every time it was over. But it's a different story today. John can play for an hour or more, totally independently.

Kirk Kilgour, 34, was perhaps the finest hitter/blocker to ever play for the U.S. National Volleyball Team. He won the NCAA Most Valuable Player Award during his college career and is a well-known coaching figure in both Europe and America. He presently coaches volleyball at Pepperdine University in Malibu, California. Kirk is a quadriplegic, but still a very competitive man who searched for close to two years for a way to play video games. Now he plays for hours at a time and can wipe out a screen of space invaders using a mouth controller. He also has a multiple game board which allows him to select from up to eight cartridges with the press of a button.

Tommy, John, and Kirk are examples of a growing number of severely handicapped people who are discovering for the first time that there is something they can do on their own that is fun. They find it a tremendous morale booster as well as an interesting way to develop the muscular skills they need in order to function. Operating the four-button joystick, for example, requires the same motion as operating a pushbutton phone or an adaptive driving panel. Operating a paddle control requires the same motion as turning a stove knob or a doorknob.

BACKGROUND

The challenge was to convert a unit that had been desinged for manual manipulation, a joystick, into a unit that could be used by someone not possessing the normal capabilities. Various ideas were experimented with including puff, suck and puff switches, telephone keypads mounted at mouth height, helmets and various types of switches. Eventually, with the help of several handicapped people and their enthusiasm for the project, a workable design was found and expanded upon. The devices allow severely handicapped people to play the very same video games that millions of other people are playing, thus making them feel less different. Since each handicap and each person is slightly different, a variety of hardware is required to suit various individuals. Many different switching devices were tried and the most versatile was found to be a soft-touch button box controller.

Most young adults with spinal cord injuries had their accidents while involved in some exciting activity. These are not sedentary people and one of their biggest mental problems is boredom. Playing video games, whether on a game console or computer, gives them a chance to be active--to respond both mentally and physically as they dodge asteroids, defend cities, or maneuver a chicken across a 10-lane highway while horns honk and engines roar.

For non-oral children who eventually will use a computer to communicate, a video game can be the first step to interaction with the computer.

One of the first abstract concepts these children have to grasp is that they can control movement on a CRT screen by pushing a button. A video game appears to be an excellent way to reinforce this concept.

MATERIALS AND METHODS

For the C 2-3 level quadraplegic, a tongue operated video game controller is availalbe. It has switches for 4 directions, a "fire" button, and a game reset and game select switch. It is made from a telephone keypad with plastic surfaces glued on the keys which are used. It can be mounted on a plate attached to a body jacket, or on a wheelchair control arm or lapboard.

For a person who has head movement, there is a mouth-operated joystick. This consists of a joystick shaped like a lollypop with a puff/suck switch mounted through its center for "firing" action. Mounted on the side of the housing is a double-throw, double-pole switch for reset and select functions.

For people who have movement of their arms, but not their hands or fingers, a controller is available with arcade-quality leaf switches activated by large buttons which require very little pressure to operate.

The button switches are applicable to a wide variety of handicaps. Amputees can use them with a hand, an arm, wrist or foot as well as with a mouthstick. People with weak muscles find them much easier to use than standard joysticks. The buttons can be placed far apart, allowing people with cerebral palsy and others with spastic or difficult-to-control momements to hit one button switch without concurrently hitting a second one. The buttons can be wired for remote operation. This allows a "fire" button to be activated by a knee or head, etc., while the directional switches are being operated by a hand, arm or foot.

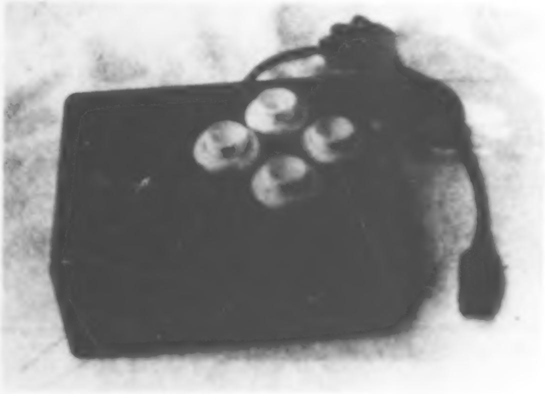

Figure 1. The Finger-Tip Controlle, found to be applicable to a wide variety of hadicaps.

For people with the desire and ability to operate a joystick, but who don't have enough strength to curl their hands, a cradle has been developed that fits over the top of a conventional joystick. The operator can push and pull it. It can be padded for extra comfort or a velcro strap can hold a hand firmly in place in the cradle. The joystick is glued to a piece of ABS plastic which is then clamped to a table with C-clamps. Remote firing and game select and reset switches can be included.

All these adaptive controllers are made from off-the-shelf items. The stands for the mouth and tongue controllers are made of ABS pipe; the button switches are purchased from a manufacturer of arcade equipment; and the mouth controllers are standard joysticks modified with puff/suck switches. The plastic boxes are purchased from a plastics company.

RESULTS

The number of individuals and institutions using this equipment which has been developed over the past two years testify to its value. People in the following locations are using these modified video game controllers to play competitively: Canada, Alaska, California, Connecticut, Florida, Illinios, Indiana, Kansas, Massachusetts, Michigan, New Jersey, New York, North Dakota, Oregon, Pennsylvania, South Dakota, Tennesee, Washington, Wisconsin.

Organizations using these controllers with their clients include: Carl Harvey School for the Physically Handicapped, Santa Ana, CA; Cerebral Palsy Center for the Bay Area, Oakland, CA; Crippled Children's Society, Pasadena, CA; Fairview State Hospital, Costa Mesa, CA; Memorial Hospital Medical Center, Long Beach, CA; Northridge Medical Center, Chatsworth, CA; Palmcrest Convalescent Hospital, Long Beach, CA; Rancho Los Amigos Hospital, Downey, CA; Santa Clara Valley Medical Center, Santa Clara, CA; Sharp Rehabilitation Center, San Diego, CA; Stanford Children's Hospital, Palo Alto, CA; Sunnyview Hospital & Rehabilitation Center, Schenectady, NY; Torrance Memorial Hospital, Torrance, CA; University of Virginia Rehabilitation Engineering Center, Charlottsville, VA.

Figure 2. Use of a head-operated video game controller keeps Tommy Garcia, a C-2 quadriplegic occupied while he is confined to bed due to a pressure sore. This controller is limited to two-directional action--either up/down or left/right and uses a puff/suck switch for "firing". One of the games it works well with is Space Invaders.

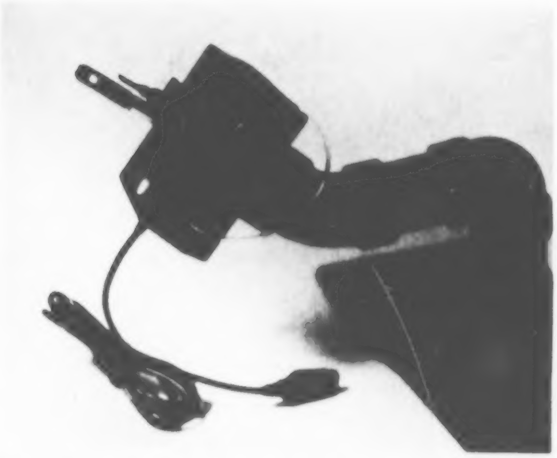

Figure 3. Mouth operated controller with lolly-pop-shaped joystick, puff/suck switch for "fire" and double-pole, double-throw switch for reset and select functions.

CONCLUSION

Sandy Blatt, a 35-year-old quadriplegic from Pittsburth, says of video games, "It's so necessary, especially when you're dealing with a disability all day long. It's great to jump on one of those machines and have a good time. It's independent recreation. It's one more way for me to become a part of society again. It makes it possible to become less of a second-class citizen and more first class. That's the bottom line for me."

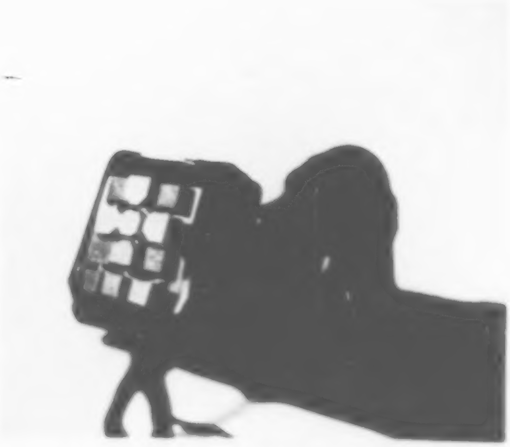

Figure 4. This tongue-operated video game controller made from a telephone push-button keypad includes game reset and select switches and can be used by people with only tongue movement.

Video games are excellent devices for rehabilitation/recreation therapy. They are self-motivating, provide exercise in motor skills, coordination and concentration, and encourage social interaction. These adaptive controllers are available now to benefit the handicapped community.

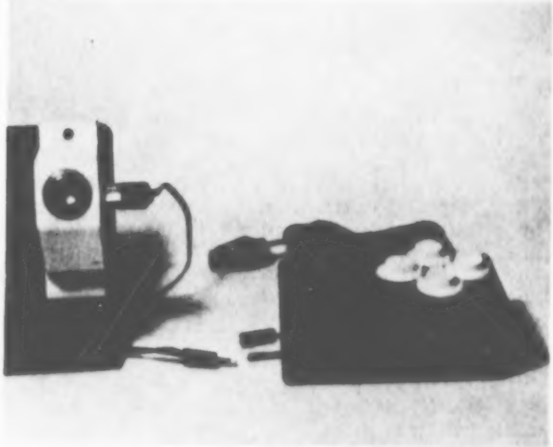

Figure 5. A FingerTip Controller with a remote firing button which can be placed at a spot convenient to the player. Good for people with muscular dystrophy, this controller requires a very slight amount of pressure to activate the switches.

ACKNOWLEDGEMENTS

I'd like to thank all the recreational therapists, rehabilitation engineers and most of all the enthusiastic handicapped people who have encouraged me and worked with me to make this equipment available. I also thank my wife, Diane, for constructing this paper.

Ken Yankelevitz
3039 East Second Street
Long Beach, CA 90803

14.3

VIDEO GAME FEEDBACK EXERCISING SYSTEM FOR A DISABLED SKID LOADER OPERATOR

Jiri J. VASA
Queen's University, Kingston, Ontario, Canada

INTRODUCTION

Late in 1980, after three years of work, we finished the modification of a Skid Loader for a farmer in our area (Fig. 1). Our client is paralyzed and can only use his elbows to operate the machine; he uses sixteen switches to start and stop the motor, to set the throttle and brake and to control the movement of the machine, the arm and the bucket.

He has been using the machine, on a regular basis, several hours per day on his farm. Unfortunately, due to the nature of his disability, he can only work in mild weather, which in our part of the country means that he is idle during the late Fall, Winter and early Spring.

Controlling the machine in the demanding environment of the farm requires considerable dexterity, which is only acquired with practice and is quickly lost in the periods of inactivity. Since winterizing the machine is not acceptable, for medical reasons, we turned our attention to possibilities of keeping the user in good physical shape when he is not using the machine.

Figure 1

BACKGROUND

An exercising machine, simulating the operation of the Loader controls was proposed. This was to be accessible from a wheelchair, with minimum adjustments required before the exercise session.

It was recognized, early in the project, that perhaps the most important problem was to ensure that the exercising system would be used regularly and that the individual switches would be operated according to some predetermined plan. We had had a similar problem with ablebodied persons and were, at that time, investigating the use of electronic games as part of the exercising equipment for the ablebodied population (see Acknowledgements). Because of our preliminary successes in that area we decided to use a similar method for the Exercising System.

MATERIALS AND METHODS

The Exercising System (Figure 2) consists of a frame and electronics system.

Frame

A welded aluminum frame is used. It is lightweight for portability; the weight of the wheelchair on the side-platforms ensures stability when the system is in use.

The arms which carry control brackets are adjustable in all directions for initial installation. The brackets, shown in the picture without their protective cover, are a duplication of the Loader brackets and hold sixteen switches corresponding to the Loader controls.

The vertical body of the frame contains a switching panel for the controls.

Electronics System

Several electronic games were tested in the prototype. All of them were of a "switch-control" rather than "potentiometer-control" type and all of them performed well.

One of the two stick controls of the game was replaced by a switching panel. The panel facilitates assigning any of the 16 switches in the elbow brackets to any of the five functions required to play the game (forward, back, left, right and "fire" button).

The second stick control is left intact for the second player.

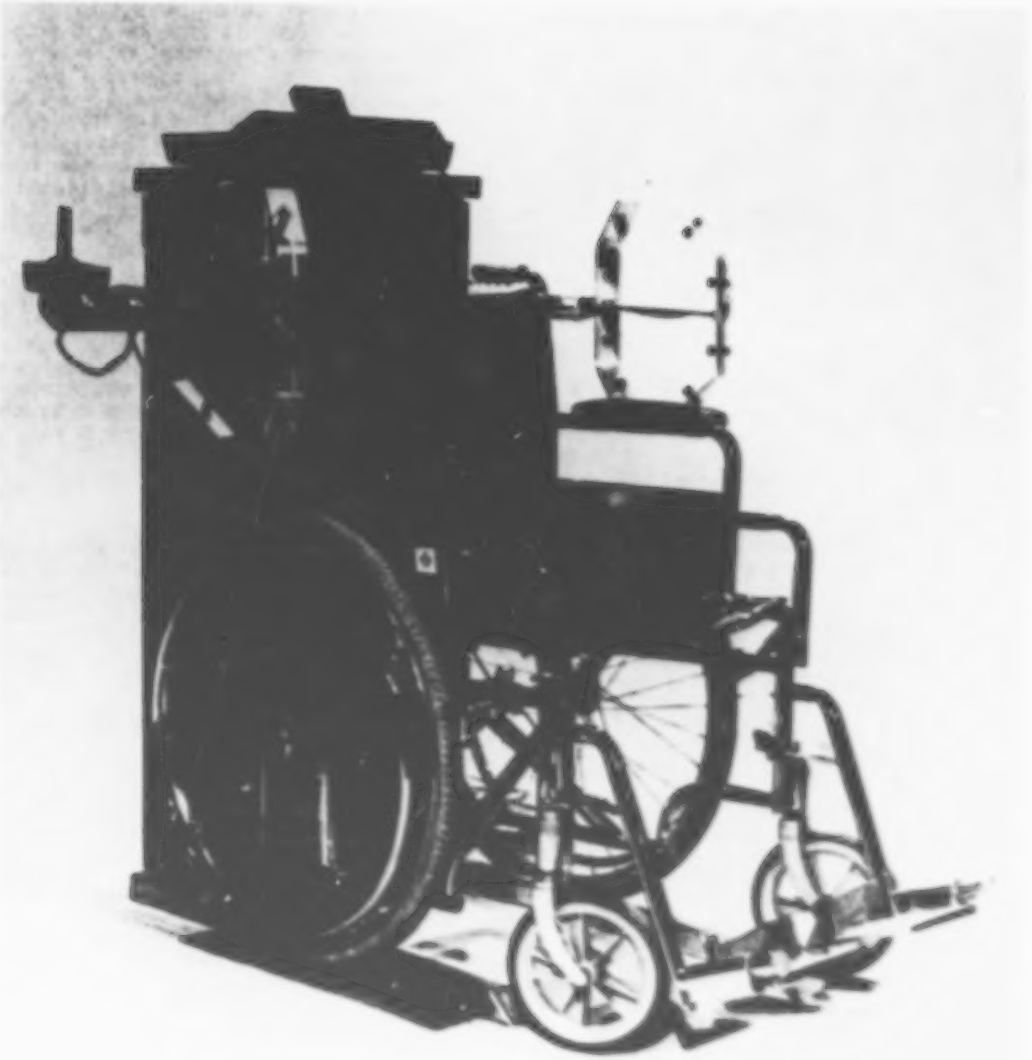

Figure 2

A protocol has been prepared for periodic switch assignment changes; this assures balanced use of switches above the horizontal support (easier task) and below (more demanding task).

Use

The exerciser is positioned in front of a television set; no special device is required, the exerciser can share a family television set. The wheelchair is backed onto the side-platforms and the brakes are set. The user then places his elbows in the control brackets and after the second player/assistant has switched the power on, selected the game and initiated it, the user can play, operating the preselected switches.

The game shown in Figure 2 was used, typically, with the tank/airplane battle cartridge. It requires only forward, left, right and fire buttons. The tank-like shape moves on the screen, turns left or right in thirty degree increments and fires from the "cannon". Additional operation of a left or right control can curve the path of the "projectile".

The game is attractive as a first-approach selection because of its independence on time. This is important for the beginner; other cartridges are available and were quickly acquired by the user (presents from his family). We do not favour the time-limit games for this application if we do not have control over the timing (see Discussion, use of a computer instead of a game).

RESULTS

The exercising system has been well received and has been used daily, since late 1982, when it was delivered. Some beneficial side-effects, such as family participation in these regular exercises have been reported. We have had no negative comments and are considering, given our original objectives, the project a success.

In the absence of an objective evaluation mechanism we will monitor the user's performance when he begins to use his Loader in the Spring.

DISCUSSION

The first electronic game we modified, in 1974, was used for recreational purposes by disabled patients in a local hospital. It was not until the year 1981 that we started to use the games as video and audio feedback for exercising equipment. The system described here is the simplest one in a series of our exercising aids for the disabled and the first one delivered and tested in a practical application.

From its conception, the shape and complexity of the system was predetermined. The location, shape and size of the operating controls are a copy of those used on the Loader and the function of the electronic game is just to encourage the user to exercise regularly and to use the whole array of switches.

We have been producing, together with this unit, two more units, with more universal applications. Their controls are adjustable in a wider range and are spring loaded. Adjustable tension and the use of shock absorbers widens the range of potential users.

On a higher level, our current development of this idea is in two directions. A system is being finalized, with a computer instead of a game; the computer provides the playing function, just as the game did, but with the option of selecting speed, size and other characteristics of the screen shapes. It also performs switch selection and periodical switch assignment modification.

The second system will serve as a simulator and will be used for the Loader operation instruction. The Loader in Figure 1 has a remote-control steering system, mainly for training purposes and we were using a close-circuit television system to train the operator. We are hoping that our new simulator will replace much of the expensive hardware and will shorten the training time.

ACKNOWLEDGEMENTS

The construction of the exerciser was supported by the Ministry of Community and Social Services, Vocational Rehabilitation Services, Belleville, Ontario, Canada.

The exerciser is based on ideas developed during the work on the Video/Audio Feedback Exercising System project, supported by the Government of Canada, Fitness and Amateur Sport.

Jiri J. VASA, P. Eng., Head,
Rehabilitation Engineering Section,
Bio-Medical Engineering,
Queen's University,
KINGSTON, Ontario K7L 3N6
CANADA

14.4

COGNITIVE RECREATIONAL VEHICLES

Fred Lakin

Rehabilitation Research and Development Center
Palo Alto Veterans Administration Medical Center

ABSTRACT

'Humans have the power to symbolize, TO MAKE EXTERNAL SYMBOLS EXPRESSING CONCEPTS -- and that's when engineering comes in' [Engelbart63]. Design of assistive devices for the manipulation of symbols is a valuable application of engineering. Almost all humans, whether cognitively 'normal' or 'disabled', need assistance with creating and storing symbols for intellectual tasks (books, computers, blackboards). Symbol manipulating systems can be viewed as 'vehicles' for navigating through information space. And, like physical vehicles, they can be used for recreational purposes -- to provide refreshing mobility in information space. This paper develops the idea of cognitive recreational vehicles, and briefly describes the GraphCom (GRAPHic COMunication environment) computer graphics system as one such vehicle tailored for the cognitively impaired.

INTRODUCTION

The thrust of this paper is the rich set of interrelations between intellectual play and work, computer graphics, and cognitive rehabilitation. To start things off, let's look at the definitions for the terms (from [Houghton76]) in the seemingly odd phrase 'cognitive recreational vehicle' .

> cognitive: 1] pertaining to the mental process or faculty by which knowledge is acquired.
>
> recreate: 1] to impart fresh life to; refresh mentally or physically.
>
> vehicle: ... 2] anything through or by which something, as thought, power, information, or the like, is conveyed, transmitted, expressed, or achieved.

By taking the broader, not necessarily physical, sense of vehicle, we find that indeed an assitive symbol manipulation system can be a cognitive vehicle: a medium for achieving the acquistion of knowledge. And as designers we can make it a goal of such a system that it refresh and impart fresh life to the cognitive activities that it supports.

The viewpoint of this paper is that cognition at whatever level is a natural and inherently satisfying human function. This is the viewpoint of the very young, to whom all learning is fun, before the idea that school is work. This is the viewpoint of certain computer information vehicle drivers, who report experiences like 'Flying at the speed of thought' [ARC73].

This is NOT the common viewpoint of the work-a-day world, where intellectual activity is something to recover from, and recreation is 'refreshment of one's mind or body after labor through diverting activity; play' [Houghton76].

BACKGROUND

People with cognitive disabilities have difficulty in using communication systems, particularly verbal and textual systems. However, many of the cognitively disabled retain pictorial processing and manipulation skills [Pontecorvo76, Fryer79b, Fryer80b]. One of the hypotheses of the GraphCom project is the assertion that a computer graphics system can be programmed to function as a personalized 'smart drawing aid' which assists users in recreational visual tasks.

Jeanne Fryer, director of the Bay Area Head Injury Recovery Center, is co-investigator in the GraphCom project. Fryer's cognitive therapy procedures are very visual, utilizing both pictorial communication rehabilitation and pictorial cognitive assessment techniques. One of Fryer's clients produced the markings which have been copied in figure 1. These marks, from left to right, are: first controlled drawing; first meaningful sign (was designated as 'yes'); and first attempt at 'H' (initial letter of client's name). The level of visual abilities demonstrated in figure 1 are the entry point into the visual recreational world of GraphCom.

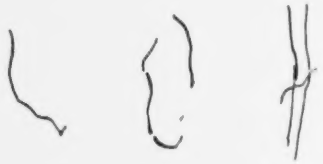

Figure 1. Graphic marks by cognitively disabled person.

The psychologist A.R. Luria invented a paper-based assistive symbol manipulation system to help a brain-damaged invidual tell a story [Luria66]. Luria called his system a 'rational external device'. The GraphCom project carries this idea one step further, asserting that such a system can also be inherently graphic (with text a kind of graphics), and, equally important, FUN.

Alan Kay, speaking of the role of computers in the offices of the future, says that what we need are 'interfaces with play value' [Kay81].

MATERIALS AND METHODS

The materials used in the GraphCom project are a powerful computer, a high-resolution graphics display, and simple yet responsive input devices. This system is described fully in [Lakin83a,83b, 83c]. The method employed in GraphCom is called 'clarifying enivronments' [Moore77]. The premise is that a user enjoying visual recreation can explore the drawing facilities of the environment, and in so doing certain visual rules obeyed by objects in the environment will be clarified for him or her. The cognitive consequences of this clarification are discussed below.

RESULTS

Two experimental versions of GraphCom have been built, and a clinical prototype is under construction. Figure 2 shows results from the display screen at the Stanford Artificial Intelligence Laboratory GraphCom facility.

Figure 2 depicts a visual and cognitive recreational activity called the 'outline game'. Figure 2a shows two visual symbols, an Occidental heart and the Chinese character 'xin', which also means heart. In figure 2b the xin symbol has been outlined in little hearts. And then in figure 2c, the pictograph from 2b has been used in turn to outline a heart. Finally in figure 2d a thin line network diagrams the nested grouping structure of the double outline pictograph in figure 2c.

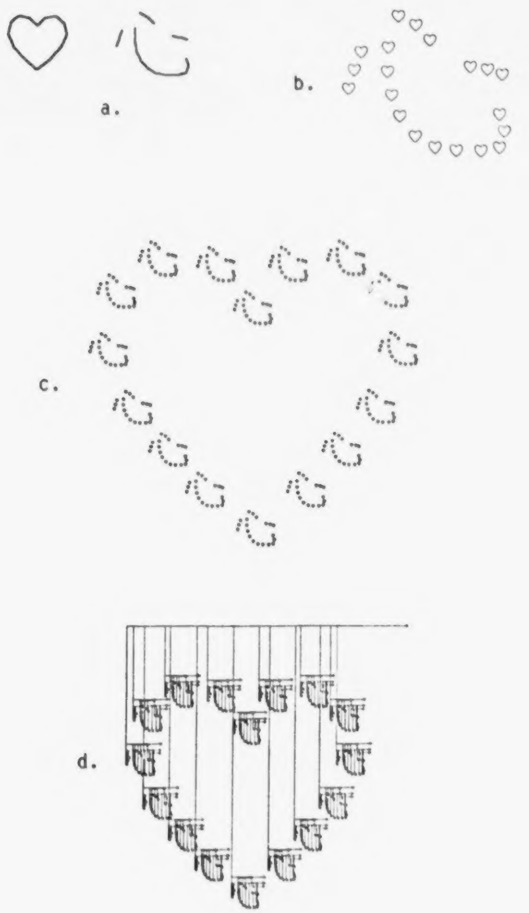

Figure 2. The 'outline game' played with hearts and Chinese characters.

The 'outline game' is a simple visual diversion, played for fun. But at the same time the user is entertained, he or she is also acquiring knowledge of the powerful visual rules which GraphCom demonstrates. One of the recreational applications of GraphCom is graphic communication. The idea of outlining a shape, and thus the tracing of symbols, is basic to all visual communication systems. It should be pointed out that Chinese characters are NOT just another kind of text; their pictographic nature means that they can be used by persons with cognitive impairments which prohibit comprehension of phonetic text [Yamadori75].

And the idea of grouping visual objects together, also learned by playing the 'outline game', is essential to most visual communication systems. Figure 3 shows how the grouping diagrams used by GraphCom can clearly show the structure of Blissymbols and the disability logo. Assistance in seeing such structures is a great help for anyone trying to learn such communication systems, particularly if they have a cognitive disability.

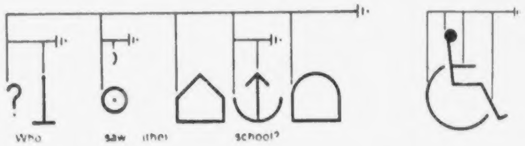

Figure 3. Grouping structures for Blissymbols and disability logo.

CONCLUSION

People have always learned easily through games. Computers permit the next development in this process, permitting cognitively impaired users to have the fun of driving a video vehicle through information space. The vehicle can be made responsive and assistive as well as fun, providing accessible experience of cognitive skills that have wide utility in communciation. Cognitive recreational vehicles are just another kind of assistive device.

ACKNOWLEDGEMENTS

The work was supported by the Palo Alto Rehabilitation R&D Center of the Veterans Administration. Figures 1 and 3 are reused courtesy of the Institute of Electrical and Electronics Engineers and first appeared in [Lakin83a].

REFERENCES

ARC73 Augmentation Research Center, a phrase heard around Engelbart's SRI lab in the early 70's.

BlissymbolicsInst79 Blissymbolics Communication Institute, "A Manner of Speaking", pamphlet, Toronto, Canada, 1979. Blissymbolics used herein dervied from the symbols described in the work SEMANTOGRAPHY, orginial copyright CK Bliss 1949. Blissymbolics Communication Institute exclusive licensee 1982.

Engelbart62 a slight paraphrase of Engelbart, D. C., "Augmenting Human Intellect: A Conceptual Framework," SRI International, Menlo Park, California, Oct 1962.

Fryer79b Fryer, Jeanne, Mackworth, N., Mackworth, J. and Teach, R., "The Two Phases Of Cognitive Recovery: Some Diagnostic And Theraputic Issues," Annual Head Trauma Conference, Santa Clara Valley Medical Center, San Jose, CA, 1979.

Fryer80b Fryer, Jeanne, "Cognitive-visual Recovery in Head Injury," Annual Meeting on Traumatic Head Injury, Virginia Medical College, Harrisburg, VA, 1980.

Houghton76 THE AMERICAN HERITAGE DICTIONARY OF THE ENGLISH LANGUAGE, William Morris, Editor, Houghton Mifflin Company, Palo Alto, 1976.

Kay81 Kay, Alan, personal communication, December 1981.

Lakin83a Lakin, Fred, "A Graphic Communication Environment for the Cognitively Disabled", presented at IEEE Spring Compcon '83, San Francisco, March 1983.

Lakin83b Lakin, Fred, "A Graphic Communication Environment For The Brain Injured Based On A Cognitive Model of Image Manipulation", invited address at HEAD TRAUMA REHABILITATION CONFERENCE: COMA TO COMMUNITY, Stanford University Medical Center, March 1983.

Lakin83c Lakin, Fred, "Measuring Text-Graphic Activity", accepted for publication in the proceedings of Graphics Interface '83, Edmonton, Alberta, May 1983.

Luria66 Luria, A.R., HUMAN BRAIN AND PSYCHOLOGICAL PROCESSES. New York, Harper & Row, 1966.

Moore77 Moore, Omar K., "The Clarifying Environments Program: 1960-1980", prepared for the Conference on Social Research Organizations, Pittsburgh, Pennsylvania, Oct 1977.

Pontecorvo76 Pontecorvo, Anthony Bartholomew, THE ROLE OF SYMBOL MANIPULATION AND PERCEPTUAL PROCESSING IN COMMUNICATION, PhD dissertation, California School of Professional Psychology, Frenso Campus, 1976

Yamadori75 Yamadori, Atsushi, "Ideogram Reading in Alexia", BRAIN p 231-238, 1975, vol 98.

ADDRESS

VA RR&D Center (153)
3801 Miranda Avenue
Palo Alto, CA 94304.

PARA-BIKE: AN ARM-POWERED BICYCLE

Douglas F. Schwandt

Rehabilitation Research and Development Center
at the Palo Alto Veterans Administration Medical Center

ABSTRACT

The Para-Bike, an arm-powered bicycle, is being developed at the Rehabilitation Research and Development (RR&D) Center, located at the Veterans Administration Medical Center, in Palo Alto, California. With the success of the current version of the Para-Bike, the development phase is nearing completion.

INTRODUCTION

Recreation and Bicycling

Once the basic recovery and living needs are attended to, recreation becomes paramount to complete rehabilitation. As a recreational activity engendering both physical and emotional vitality, bicycling is particularly appropriate for an individual facing barriers in mobility and participation.

An arm-powered bicycle may be used for a wide variety of recreational, therapeutic and transportational purposes, including exercise, relaxation, improvement of balance, instant feedback on physical accomplishment, excitement of competition, commuting, pleasure of interacting with family and friends, and the exploration of the countryside and one's independence.

DEVELOPMENT OF THE PARA-BIKE

Now completing the development phase at the Rehabilitation Research and Development Center, the arm-powered Para-Bike began as a VA sponsored design project in the Stanford University Design Division masters program under the auspices of the RR&D Center. Four prototypes of the Para-Bike have been completed to date.

Para-Bike Features

The Para-Bike has incorporated design features from various types of vehicles, including standard bicycles, innovative human powered vehicles and sport wheelchairs.

Drive System and Rider/Vehicle Interface. A hand-cranked chainwheel and chain linkage to the front wheel replace handlebars, combining the propulsion and steering mechanisms. Back pedaling activates caliper brakes on both the front and back wheels. A large (48 tooth) sprocket adaptation to the standard 10 speed bicycle freewheel has been added to provide for a dramatic reduction in the low end of the gearing for hill climbing, without sacrificing the higher gear range necessary for higher cruising speeds.

The rider sits at about wheelchair height in order to see through car windows and to facilitate transfer. The legs straddle the drive tower above the 14 inch diameter front wheel. The drive chain is routed close to the drive tower, reducing the inside clearance necessary between the legs. Synthetic canvas is stretched between the tubes of the seat frame and semi-reclined backrest, similar to the arrangement on a typical wheelchair.

The cranks tilt forward out of the way for transferring, so the rider may sit first, and then

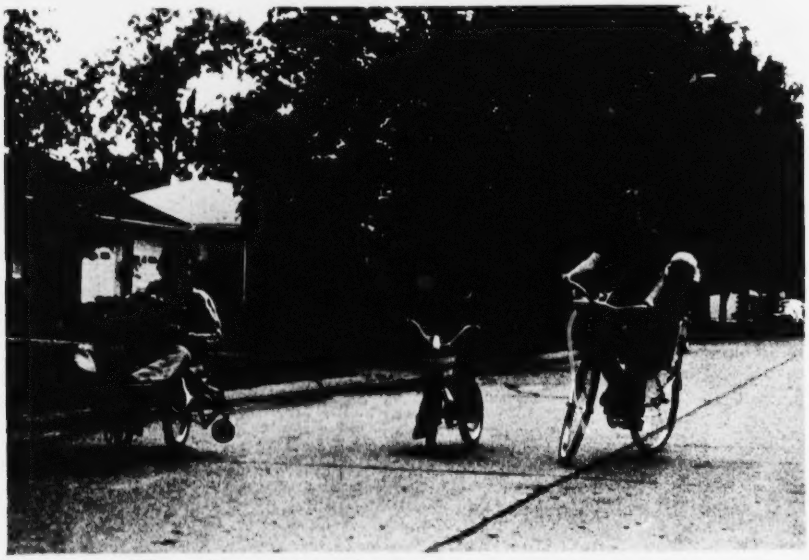

Figure 1. Mike Delaney takes the Para-Bike on a bicycle ride with his wife Kathy and their two daughters, Becky and Christy.

lift a leg over to the other side of the drive tower. The seat tubes have been cushioned to reduce the possibility of skin trauma during transfer.

Steering And Balance. The dynamics of a bicycle are unique. A bicycle has the remarkable quality of moving in unison with the rider, leaning into turns as an extension of the rider's motion. While a bicycle is in motion, it may be balanced by either continuous ajustments in the lean of the frame or steering of the front wheel. At one extreme is the common practice of riding a bicycle without hands. The Para-Bike operates at the other extreme, the rider maintaining balance by continually steering into the direction the Para-Bike happens to be leaning. Therefore, the rider does not need to lean the Para-Bike to balance it (such leaning is discouraged as it usually interferes with the steering control). This allows individuals with limited trunk stability to successfully control the Para-Bike lean, simply by steering.

The pedal cranks are placed so that they extend away from the pedaling axis in the same direction, instead of being offset by 180 degrees as on standard bicycles. This improves steering control which reduces overall effort, as less energy is required for steering.

Tipping Stability When Coming to a Stop. The natural tendency of a bicycle to balance and self steer diminish at slower speeds. People who have the use of their legs may place a foot on the ground to help balance when coming to a stop. On the Para-Bike, either the rider needs to be able to put a hand (protected with a glove and wrist guard) to the ground for support, or have some form of outrigger to provide the desired stability when starting or stopping.

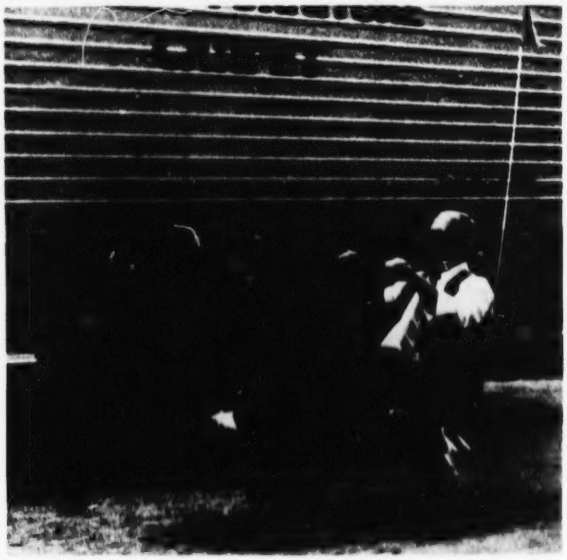

Figure 2. Wheelchair marathoner Lee Doser rides Para-Bike for the first time.

On Para-Bike I (finished in June 1980), the rider sat low enough to comfortably reach the ground. As a precaution, spherically shaped rollerskate wheels were mounted to either side of the rider, ready to touch down at the maximum desired lean.

Para-Bike II was designed to participate in the International Human Powered Speed Championships (Pamona, CA, May 1981) with an aerodynamic streamlining shell to reduce air drag. Because of the higher speeds, it was especially important that the Para-Bike not tip over. As a precaution, the side wheels were positioned to limit the amount of lean to 10 degrees from the vertical. With this conservative side wheel arrangement, the rider did not have to use a hand on the ground when coming to a stop.

The low rider profile was a concern because of the limited visibility. With the experience gained from Para-Bike II with side wheels alone to prevent overturning, the seat was raised on Para-Bike III (finished in May 1982) so that the rider would be able to see through car windows for enhanced visibility.

The side wheels on Para-Bike III:

1) are castered so as not to interfere with steering;
2) elevate for straight tracking when they are not needed;
3) move laterally outward to add to the stability during leaning in the same way an individual extends an arm for protection when falling to one side;
4) have a sprung suspension for a smooth touchdown;
5) are adjustable for the total amount of lean desired;
6) may be pulled down tight by backpedaling so that the Para-Bike is steady and level for transferring, or to provide a non-leaning ride when desired.

Para-Bike IV (Figures 1 & 2) has the same side wheel arrangement as Para-Bike III, except that the rider uses a hand lever and latch arrangement to fasten the side wheels down to prevent leaning (backpedaling is used for braking, as mentioned above). A turnbuckle allows the rider to vary the total amount of lean, so that beginners may restrict the lean while learning to balance.

Maneuverability and Portability. The front wheel may be turned just beyond 180 degrees to the left before the chain contacts the frame tubing, thereby allowing the rider to drive the Para-Bike backwards.

The Para-Bike may be turned around in a hallway just wider than its overall length (currently 58 inches). Because of its short wheelbase (33.5 inches) and the ability to turn the front wheel around 180 degrees to the left, the Para-Bike may also be turned around on a sidewalk that is about three feet wide.

The tight turning ability, and other characteristics, such as the ability to prevent leaning when desired by fastening the side wheels down, the narrow overall width of 25 inches when the side wheels are fastened down, and the ability to back up, enhance the maneuverability of the Para-Bike in tight spaces. It has performed successfully in many places a wheelchair can go, such as up ramps, indoors, and in and out of elevators.

The weights of the Para-Bike prototypes I, II, III and IV are 42, 32, 60 and 47 pounds, respectively. The weight is largely a function of the sophistification of the various features, including the sidewheels, the ability to tilt the crank tower forward for easier transfer and the choice of bicycle components. Some features are expected to be options depending upon rider preference and the type and extent of disability.

Safety. Various components including reflectors, lights, flags, chainguard, seat belt, and a horn are added to the Para-Bike for rider safety.

RESULTS

The Para-Bike prototypes have been tested by many individuals with various levels of disability. The Para-Bike is primarily intended for paraplegics and lower limb amputees; however, individuals with low level quadriplegia have successfully operated the Para-Bike independently.

One low level quadriplegic has limited grip, minimal tricept function, and reduced trunk stability. He was able to transfer on and off of the Para-Bike independently, and although he had some difficulty with the combined pedaling and steering, he immediately acquired the skill of balancing the Para-Bike by steering during coasting. Another individual had no difficulty pedaling the Para-Bike, but his balance was affected by his disabilty, and he had difficulty keeping the Para-Bike on two wheels. However, after approximately 45 minutes of training, there were perceptible improvements in his balance control of the Para-Bike, and he found this to be very gratifying.

A young man with cerebral palsy, and an older man with paraplegia, both customarily driving electric wheelchairs, rode the Para-Bike as a four wheeler with the side wheels fastened down for no lean. They both enjoyed the physical exertion and the mobility independent of auxiliary power. Another individual, paralyzed as an infant, had never ridden a bicycle until recently when he had an opportunity to ride the Para-Bike.

Mike Delaney recently went for a bike ride with his wife Kathy and their two daughters, Becky and Christy (Figure 1). Wheelchair marathoner Lee Doser sees the Para-Bike as an excellent racing vehicle (Figure 2).

CURRENT STATUS

With the success of the current version of the Para-Bike, the development phase is nearing completion. Further evaluation and minor modification are underway, and the Para-Bike should soon be ready for an initial production.

TANDEM DEVELOPMENT

The building has begun on a prototype tandem for the disabled and able-bodied to ride together. Conceptually, the bicycle tandem consists of merging the Para-Bike front with a standard bicycle in the back. This tandem prototype is expected to be finished by the end of March, 1983.

COOPERATION & SPONSORSHIP

The Northern California Chapters of the Telephone Pioneers of America sponsored Para-Bike II and the travel to the International Human Powered Vehicle Championships (Pamona, May 1981), where Asher Williams, a United States veteran with incomplete quadriplegia set the new world record for arm-powered speed of 25 mph. Marshal Smith, from Vancouver, B.C., a paraplegic in his mid-fifties, turned in a speed of 24 mph. Marshal has long been a bicycling enthusiast, including bicycle tours of Europe. His bicycling activity was interrupted by paralysis several years ago. He now enjoys the opportunity with the Para-Bike to be back on a bicycle.

A cooperative project between the RR&D Center and the University of British Columbia Athletic and Sport Services Department (under a grant from the British Columbia program for the International Year of the Disabled Person) to develop alternative cycles for the disabled has provided funding and other support for Para-Bikes III and IV, and the development of the tamdem for the disabled and able-bodied to ride together.

PUBLICATIONS

Schwandt, Douglas F., "Para-Bike - A Recreational Bicycle for Individuals Who Do Not Have the Use of Their Legs", 1981 Proceedings of the 4th Annual Conference On Rehabilitation Engineering, Washington D.C., published by the Rehabilitation Engineering Society of North America, pp. 61-63.

Schwandt, Doug, "Para-Bike", Sports 'n Spokes, The Magazine for Wheelchair Sports and Recreation, Pheonix, Arizona, November/December, 1980, pp. 18, 19 and 21.

For further information contact:

Douglas Schwandt
Rehabilitation Research
and Development Center (MS 153)
Veterans Administration Medical Center
3801 Miranda Avenue
Palo Alto, California 94304
(415) 493-5000, ext. 4473

FROM RESEARCH AND DEVELOPMENT TO A COMMERCIALLY AVAILABLE DEVICE A CASE STUDY ON THE ARROYA DOWNHILL SKIING SYSTEM FOR PERSONS WITH DISABILITIES

PETER W. AXELSON M.S.M.E.

REHABILITATION RESEARCH AND DEVELOPMENT CENTER
at the VETERANS ADMINISTRATION MEDICAL CENTER
Palo Alto, California

The ARROYA is a downhill skiing system for persons with disabilities. The user of the ARROYA is able to manifest control over direction and velocity of the skiing system by shifting his or her weight and by using appropriate arm movements. The controllability and maneuverability of the ARROYA has resulted in the creation of an integrative sport in which persons with varying disabilities are able to compete in national and international slalom, giant slalom, downhill and freestyle skiing events and competitions.

The purpose of this article is not to define the characteristics of the ARROYA skiing system (for more detailed information on the ARROYA skiing system refer to the references at the end of this article). This article will examine the characteristics of the design development process utilized in developing the ARROYA and why it resulted in a commercially available product. The shortcomings of this project will briefly be examined as well.

First, a brief chronological history of the development of the ARROYA skiing system will be given to orient the reader to the project and the time frame of development. In addition, the following aspects of the design process are thought to be somewhat responsible for the development of commercially available devices and will be discussed:

> The use of Design Development Guidelines - Particularly the definition of the need, the use of design specifications and design alternatives.
>
> Variations to Standard Research Methodology Especially the high degree of user involvement in the design process, the large portion of time devoted to testing and evaluation and significant interaction with various manufacturers.
>
> The unique resources that were available to this development project - specifically in terms of human, physical and financial resources.

A CHRONOLOGICAL HISTORY

DECEMBER 1977
The need for a sledding device with improved directional and velocity control was identified after testing a Norweigen Pulk at Winter Park Ski Area in Colorado.

MARCH 1978
A prototype sled was carved out of urethane foam and fiberglassed. Testing was performed at Winter Park ski area in March of 1978 with and without a ski bolted onto the bottom of the ARROYA I. Without the ski, the device represented an improvement in directional control over the Norweigen Pulk.

DECEMBER 1978
Inward facing edges were placed on the underside of the ARROYA II which facilitated increased directional and velocity control.

MARCH 1979
The ARROYA II was demonstrated at the National Handicapped Ski Championships in the freestyle event. The device was left at Winter Park Ski area where 14 users tested and evaluated the sled.

JUNE 1979
Based on testing and evaluation performed at Winter Park Ski area, two ARROYA III's were completed in partial fullfillment of a Product Design curriculum course at Stanford University.

JULY 1979
The ARROYA III was successfully tested on glaciers along the Continental Divide in Colorado. The company ARROYA was formed to facilitate the economic production of ARROYA IV prototypes for evlauation by the Veterans Administration.

DECEMBER 1979
Fifteen ARROYA IV prototypes were distributed amongst four downhill skiing programs for persons with disabilities. Instructional clinics were run at each of the ski areas where testing and evaluation was facilitated by evaluation protocall and through objective questionnaires.

MARCH 1980
Fourteen competitors raced in slalom, giant slalom and freestyle ARROYA skiing events at the National Handicapped Ski Championships at Winter Park ski area in Colorado.

FEBRUARY 1981
Based upon field testing and analysis of the objective questionnaires, improvements were made in the design of the skiing system. The ARROYA V was introduced at the testing and evaluation centers which had previously utilized the ARROYA IV's.

MARCH 1981
Thirty four persons with disabilities competed in slalom, giant slalom and downhill ARROYA skiing events at the National Handicapped Ski Championships at Winter Park ski area in Colorado.

OCTOBER 1981
The ARROYA development project was completed at the Rehabilitation Research and Development Center (RRanD) at the Veterans Admini-

stration Medical Cener in Palo Alto, California after User/Instructor manuals were distributed to all known handicapped skiing programs in the United States and Europe. Certification guidelines for users and instructors were distributed as well. A final progress report and drawings were distributed to all potential manufacturers interested in the ARROYA project.

MARCH 1982
Forty-one competitors raced at the National Handicapped Skiing Championships in slalom, giant slalom and downhill sit skiing events. A decision was made to have regional qualification races to decrease the number of racing entrants in 1983.

DECEMBER 1983
The ARROYA VI is introduced by BENEFICIAL DESIGNS INC. with improvements in durability and controllability over the ARROYA V.

THE USE OF DESIGN DEVELOPMENT GUIDELINES

The use of design development guidelines facilitated the identification of a specific need which in turn led to a well defined problem definition. The researcher was academically forced to determine design specifications which enabled objective evaluation of the tested design alternatives. A thorough state of the art review ensured that research efforts were not retracing prior work done in the field. The budget, resources and methodology are also part of the design development guidelines but will be discussed in the next section of this paper.

The need
A global need for recreational equipment for persons with disablities was identified. Subsequently the specific need for an interactive sport which facilitates mobility in a winter environment was identified.

The Problem Definition
From the researcher's perspective, the problem was to create a skiing system that would facilitate the integration of disabled persons with the traditional downhill skiing environment.

The Design Specifications
Design specifications with numerical values were determined as objectives for the utimate device. Some of the specifications that were determined on 10 April 1979, prior to the development of ARROYA III were:

Physical Dimensions -
A maximum length of 1.47 meters
A maximum width of 0.46 meter
(to allow chairlift compatibility)

Weight - 6.8 kg (15 pounds) maximum.

Foot Print Pressure - 13.8 kN/m (2 lbs/in)

Turning radius - 2 m. at 4 m./sec.

State of the Art Review
Several skiing devices were identified and examined according to the design criteria. It was determined that the primary reason prior art was not successful was the lack of chairlift compatability and poor directional and velocity control.

METHODOLOGY

Designer Involvement with the Project
The design team leader in this case was directly involved in all aspects of the design process. This meant that the investigator worked with the materials himself to gain an understanding of what could and could not be done with composite materials.

Testing and Evaluation

Site Selection
In this case the investigator traveled from Palo Alto, California to the largest and most cooperative Handicapped Skiing Program in the world at Winter Park Ski Area in Colorado. This choice represented a testing and evaluation facility that had excellent snow conditions, a variety of skiing terrain, cooperative lift maintenance, ski patrol and administrative personnel, and full time proffessional ski instruction for persons with disabilities. Winter Park Ski area alone worked with 200 ARROYA skiers during the 1980 - 1981 ski season. Three other evaluation centers were chosen for their differences in geography and program philosophy.

Chairlift Compatability
One trip alone was made to record the dimensional characteristics of the various chairlifts to ensure that new designs would be compatible with at least 95% of the chairlifts.

Year Round Testing
With the assistance of four wheel drive vehicles, testing was performed on glaciers along the continental divide during the summer in order to keep the design process moving throughout the year.

User/Instructor Clinics
Both dry-land and on-the-hill instructor and user clinics were run at the four testing and evaluation centers to educate users, instructors, chairlift personnel, ski patrol personnel, and ski area management on all aspects of the ARROYA downhill skiing system. An emphasis on safety with regard to chairlift loading, unloading and evacuation procedures was taught to everyone working with the ARROYA. In addition handicapped ski program instructors had to learn about the physiological characteristics of persons with spinal cord injuries, the primary users of the ARROYA.

Evaluation Protocol
The evaluation centers were required to fol-

low protocol developed by the RRanD design team. Since most people are not able to provide objective feedback unless specifically prompted, objective questionnaires were developed. Users and instructors were required to fill out questionnaires and sign the appropriate human consent forms. Very specific questions concerning all aspects of the sled design led to the improvements in the ARROYA V. Although not required, most of the evaluation centers were involved in the editing of the User/Instructor Manual that RRanD published in October of 1981.

Telephone Evaluation

BENEFICIAL DESIGNS INC. questioned, by telephone, each user and program utilizing an ARROYA V. The information obtained from their survey led to the increased durability and performance characteristics of the ARROYA VI.

Interaction with Manufacturers

The investigator interacted with manufacturers of products similar to the ARROYA, industries using similar technologies and manufacturers of components similar to those used in the ARROYA. By using the telephone and traveling if necessary, it was possible to learn a great deal about materials and fabrication techniques without having to learn by trial and error (some trial and error learning made it easier to communicate with specialists in the field). Commercially available products would not have resulted if a manufacturer was looked for after the development work was completed.

RESOURCES

Human

The most beneficial aspect of this design development project was the high degree of involvement with users. The chart below indicates some ball park guesses as to the number of hours spent on research and development, construction of prototypes and testing and evaluation:

ARROYA I (1 unit)

Research	80 hours	36%
Prototype Construction	100 hours	46%
Testing	40 hours	18%
Total	220 hours	100%

ARROYA II (1 unit)

Research	80 hours	40%
Prototype Construction	40 hours	20%
Testing	24 hours	12%
Volunteer Skier Testing	56 hours	28%
Total	200 hours	100%

ARROYA III (2 units)

Research	320 hours	32%
Prototype Construction	640 hours	64%
Glacier Testing	40 hours	4%
Total	1000 hours	100%

ARROYA IV (15 units)

Research	500 hours	9%
Prototype Construction	1420 hours	25%
Testing and Evaluation	1560 hours	28%
Volunteer Skier Testing	2160 hours	38%
Total	5640 hours	100%

ARROYA V (10 units)

Research	480 hours	8%
Prototype Construcion	1280 hours	21%
Testing and Evaluation	960 hours	15%
Volunteer Skier Testing	3456 hours	56%
Total	6176 hours	100%

Technical expertise was obtained through industrial and university sources. At Stanford University (nearby the RRanD Center) professors of aeronautics and astronautics, materials, composites, mechanics and design were sought out for advice and consultation while the investigator was a student. Local bay area industries were consulted with regard to materials and manufacturing processes as mentioned earlier.

Legal expertise was an important aspect of the project. An understanding of the concepts involved in product liability was essential in developing a responsible attitude with regard to all aspects of the ARROYA project. A course on Products Liability was offered at Stanford University which brought in defending and prosecuting attorneys (see references for text information). The investigator chose to write his own patent based upon concepts proven in the ARROYA II prototype. A patent attorney was hired to assist in formalizing the writing style and to promote an understanding of the concept of claims. Business expertise was obtained from friends who are lawyers specializing in the estabilishment of corporate manufacturing facilities.

Financial

A key ingredient that made this design development project happen was that the principle investigator was somewhat financially independent. Being a disabled veteran enrolled in a vocational rehabilitation program which covered educational costs enabled him to spend more time on the ARROYA project than possible for a working student. To give some idea of the costs involved in developing the ARROYA some approximations are listed below:

ARROYA I (1 unit)	AXELSON	V.A.	VOLUNTEER
Materials	$500		
Travel	$600		
Labor	220 hours		

ARROYA II (1 unit)	AXELSON	V.A.	VOLUNTEER
Materials	$500		
Travel	$1200		
Labor	200 hours		

ARROYA III (2 units)	AXELSON	V.A.	VOLUNTEER
Materials		$2,000	
Travel	$1200		
Labor	1000 hours		

ARROYA IV (20 units)	AXELSON	V.A.	VOLUNTEER
Materials	$3500	$9000	$3000
Travel	$2000	$3500	(sales)
Labor **	1480 hours	2000 hrs.	2160 hours

ARROYA V			
Materials	$11000	$9800	$44000
Travel	$5000	$600	(sales)
Labor **	720 hours	2000 hrs.	4556 hours
TOTAL $	$25500	$61900	$47000

** 2000 hours paid for by the V.A. as salary to AXELSON, aproximately $18,000 for year one and $19,000 for year two (2000 hours each year aproximately).

The first two prototypes, ARROYA I and II were developed during the investigator's free time while he was a student at Stanford University. The ARROYA III was developed as a student project while a student at Stanford. The availability of V.A. monies at Stanford for student design projects was essential for initiating rehabilitation projects and served to draw young designers into the field. The development of ARROYA's IV and V was partially funded by the RRanD Center core budget.

The ARROYA design development project requested funding from the Veterans Administration merit review board. It is this researcher's understanding that the proposal was not funded because it was not basic research and it was therefore difficult for researchers to evaluate the validity of this design development proposal (which was written in a research proposal format). The Veterans Administration's merit review system is currently writing design development proposal guidelines which should improve the submission and review process for such proposals.

FUTURE

The ARROYA VI has been performing well in field testing and evaluation. Three other manufacturers to date are developing and marketing downhill skiing systems in the United States; Mountain Smith Incorporated, Mountain Man Incorporated and Quadra Wheelchairs Incorporated. A Canadian manufacturer, Nimbus Paddles International, is developing a sit-skiing apparatus as well.

There is a need for monies to fund the development of improved control surfaces for downhill skiing systems. The lack of funding to facilitate the implementation of certification protocol for instructors and users is currently causing problems for this sport which is in need of credibility as enthusiastic skiers push the sport on reluctant and uneducated ski area management.

As new sit-skiing designs are developed there is a need for safety standards with regard to chairlift compatibility and evacuation procedures. It is hopeful that the sit-skier can be recognized as a responsible user of a device with limitations that is capable of successfully integrating into a downhill skiing environment.

CONCLUSION

Through the use of design development guidelines, design methodology which emphasized a large amount of field testing and some unique resources, the ARROYA concept has evolved from a design concept to a commercially available device in less than five years.

REFERENCES

Weinstein, A.S., Twerski, A.D., Piehler, H.R., Donaher, W.A., Products Liability and the Reasonably Safe Product, A Guide for Management, Design and Marketing, John Wiley and Sons Inc. 1978.

McKim R.H. and Leifer L.J., Codirectors of the Product Design Program at Stanford University 1978 - 1979.

Axelson P.W. - Principle Investigator Development/Evaluation of a Downhill Ski-Sledding System for Disabled, A Proposal to the Veterans Administration Merit Review Board, 21 October 1981. Copies available from the RRanD Center.

Axelson, P.W., Adaptive Equipment to Facilitate Integrative Recreational Sporting Activities for Persons with Disabilities. Instrucional Workshop on Daily Living at the 5th Annual Conference on Rehabilitation Engineering August 20 - 26 1982.

Axelson, P.W., Development and Evaluation of the ARROYA Dowhnhill Ski-Sledding System for Persons with Disabilities at the 4th Annual Conference on Rehabilitation Engineering, August 30 - 3 September 1981.

Axelson, P.W., Ski Sled for Paraplegics, Bulletin of Prosthetics Research, Rehabilitative Engineering Research and Development, Spring 1980.

Manufacturer of the ARROYA skiing system:
BENEFICIAL DESIGNS INC.
5858 Empire Grade Road
Santa Cruz, CA 95060 (408) 429-8447

SPONSOR

Rehabilitation Research & Development Center
V.A. Medical Center / 153
3801 Miranda Avenue
Palo Alto, CA 94304
(415) 493-5000 ext. 4807

A FASTER SPORTS WHEELCHAIR?

Nigel G. Shapcott, R.E. and Michael J. Heinrich, R.E.

University of Tennessee Center for the Health Sciences
Rehabilitation Engineering Program
Memphis, Tennessee

ABSTRACT

The original purpose of this project was to design and develop a device to make wheelchair propulsion on sideways-sloping sidewalks more efficient. Prototypes have been constructed which demonstrate the feasibility of fitting a wheelchair with moveable pads which operate steerable front castors to achieve increased efficiency.

It has become apparent during the development of this device that the same principle has potential to significantly increase the performance of wheelchair athletes participating in track events over distances greater than 100 meters.

INTRODUCTION

The original research and development work on this project was carried out at the University of Dundee School of Bioengineering, Scotland (1).

Wheelchairs, with the exception of walking sticks, are the commonest mobility aid prescribed by the National Health Service in Britain (2). There are some 210,000 wheelchairs currently on issue from the Department of Health and Social Security in England and approximately 255,000 in the United Kingdom (3). However, the proportion of wheelchair users who use their chairs outdoors on a regular basis is small, around 5% (4). This is in part due to shortcomings in wheelchair design and performance, 77% of those interviewed perceived mobility as a limitation (4).

DEFINITION OF THE PROBLEM

When using the wheelchair outdoors, problems are encountered when the user is faced with negotiating sloping, cambered and uneven surfaces. The wheelchair tends to run down the direction of the slope, which when on a sidewalk will be off the edge and into the road.

The wheelchair is very sensitive to these cambers/cross slopes. The Centre of Gravity of the occupied chair is forward of the large wheels, resulting in forces on the castors when the chair is on a slope. Since castors are designed to be sensitive to horizontal forces applied to their mounting, the overall effect is to make the chair travel down the slope.

When the wheelchair is occupant-propelled, the continual need to compensate for unwanted downhill travel either by braking the uphill wheel or extra pushing on the downhill wheel causes unnecessary fatigue. McLaurin et. al. state that "this results in extra work to maintain direction, (about 20% for a 2° slope) and is inherently dangerous in crossing driveway cuts since this can direct the wheelchair into the street" (5).

Weber et. al., when referring to powered wheelchairs also note that, "sidewalks sloped towards the street for drainage make it particularly difficult to maintain the chair's direction as the castors tend to turn with the slope and direct the chair towards the street. Inclined surfaces sufficiently sloped to affect a chair's direction to travel are common. Sidewalks are generally sloped toward the street to faciliate drainage, and driveways crossing sidewalks produce local increases in the slope of the surface and a greater deflection of the chair. Such conditions are potentially dangerous because they divert the chair toward the street, curb, and traffic. Local fluctuations in surfaces also produce random changes in a chair's direction and must be countered if a straight path is to be maintained" (6).

PROTOTYPE

Methods of solving this problem have been attempted, [McLaurin (5), and Booth (3)] which involve placing the axis of the main drive wheels beneath the center of gravity of the wheelchair and occupant combination.

Other methods have involved the development of steering devices to counter this effect (7, 8, 9, 10). However these methods were incorporated into new types of wheelchair designs and were not designed to compliment the standard wheelchair.

The approach adopted here was to modify the standard wheelchair, rather than to design a new wheelchair, by the addition of a steering mechanism for the castors. The assumption being that there would be fewer obstacles to successfully producing and marketing a device of this type.

A list of design specifications was drawn up for the first prototype, a method of steering the wheelchair is required which:

- (a) can be operated with minimal effort;
- (b) allows control of the tendency to run down slopes;
- (c) is simple and comfortable to use;
- (d) is safe;
- (e) can be engaged easily for outdoor use and disengaged easily for indoor use;
- (f) does not interfere with other important characteristics of the chair.

The first prototype (Fig. 1) was based on standard 7" wheelchair castors provided with an additional coaxial set of bearings and to which was added a self engaging mechanism. With this engagement latch in place, the whole unit can be rotated in the modified castor mount by a control cable attached to a connector lug. The latch pivot is spring biased to give positive engagement/disengagement action.

Use is made of the castor action by allowing the unsteered castor to follow the direction defined by the steered castor. To turn to the right, the right hand castor is rotated to the right and the left hand castor follows, and vice versa for steering to the left. Each side of the chair has its own steering mechanism and the need for a relatively complex linkage between the castors has been avoided. This also has the advantage that chair folding is unaffected. Operation of the steering units is by means of pads mounted on the left and right chair back support tubes.

The optimum pad position was found to be at each side of the trunk, immediately beneath the axilla.

The body operated pads were originally mounted with a vertical pivot axis, with a facility enabling them to be swung out of the way when not in use. It became apparent that although non-disabled people could operate such levers with the side of the chest, our disabled 'test pilot' (C6) could not. The axis of rotation was pivoted through 90° as a result of this observation and operation was easier. Unfortunately because of this change the pads had to be permanently mounted in this model and could not be swivelled out of the way when not in use.

PRELIMINARY EVALUATION

An informal and admittedly simplistic evaluation of this prototype was carried out on seven volunteers.

Comments

From this test and the comments of volunteers, it was confirmed that the device enables cambers to be negotiated more easily than in a standard wheelchair and that in most cases steeper cambers can be negotiated.

Limitations of the test prototype included the fact that the steering mechanism was permanently attached and was not transferable to the user's chair with which he/she was familiar and which fitted him/her. That the pads could not be turned out of the way was viewed as a serious disadvantage. The range of pad position adjustment was found to be inadequate and a need was identified for more care in designing pad swivel bearings to minimize friction losses.

Second Prototype

The experience gained during the development and the test enabled more detailed specifications to be made for a pre-production prototype. A small additional grant was received for the purpose of having this made in conjunction with a local manufacturing engineering company. Because of the relatively large numbers of Zimmer (now Carters, the almost exact equivalent of Everest and Jenning's) wheelchairs being issued and/or purchased privately, in Britain, it was decided also to develop the pre-production prototype in a form suitable for attachment to a standard Carters chair. The additional specifications are listed below.

Pre-Production Prototype Specifications

1. The device must be able to bolt on to an existing wheelchair; the chair retaining its original castors.
2. Low friction bearings to be used at the pad swivel and a low friction bowden cable.
3. The pad swivel mechanism to be mounted to the rear of the backrest, with lever arms positioned so as not to obstruct access to hand rims.
4. The pad to be able to swing clear to the rear of the backrest when not required. No fine control or grip should be required to achieve this.
5. Position of each pad to be adjustable at the bolt-on stage, approximate range 100 mm (4 inches) in the vertical and range 50 mm (2 inches) in horizontal to accommodate different sizes of user.
6. The same 'independent castor' steering geometry to be retained.
7. Pads to be lightly sprung upright.
8. The wheelchair to retain its original overall dimensions when folded.
9. Bowden cables to be reliably anchored with simple adjustment mechanisms.
10. Castor steering unit to be controlled by two cables.

Rationale for specification 10 was to:

> assist in curb climbing by keeping the castors pointing forward when they are tilted up onto the curb;
>
> improve steering safety by ensuring that there is always one steering castor in contact with the ground when bumpy surfaces are being negotiated.
>
> it is such that the original 'one pad, one cable' layout can be reverted to simply by removing the extra cable.

RESULTS

A design has been developed which meets the above specification and which is adaptable as a bolt-on unit to suit a range of wheelchairs in common use including DHSS 8LJ, Vessa, Everest and Jennings and Carters (OEC). Two prototypes have been made and subjected to initial tests.

No formal evaluation has been made of this second prototype due to lack of resources. Although the bolt-on concept works, informal evaluation has shown that two cable operation for each castor results in bulky, heavier, more expensive units at the castors and pads with few advantages over the simple one cable system.

SAFETY

As aspect of the system designed in from the beginning involves inherent safety. Since the inside (of the turn) castor turns the wheelchair, if an attempt is made to turn too quickly the inside wheel will lift off, thus steering effect is removed and the wheelchair will stop turning until the wheel makes firm contact. Also the direction of lean to operate the steering is natural, i.e. into the turn, which helps increase stability of th vehicle.

DISCUSSION

Although mechanical work on the project has slowed down, paperwork has continued to be relentlessly generated and the concept has now been granted U.S.A. Patent 4,364,580 (11).

During a brief discussion on the steering wheelchair concept, George Murray who recently wheeled himself across the USA from coast to coast, pointed out the potential of such a device for wheelchair races (12). For a one mile race, his time is approximately on minute faster for a straight mile compared with one mile run on a traditional 400 meter track due to the ability to propel continuously with both arms.

A U.S. company is now being set up to further develop and market this device initially aiming at the wheelchair athletes in the USA.

The device will be light weight, unobtrusive, and will be a bolt-on accessory, and will accommodate the existing wheelchair castors.

ACKNOWLEDGEMENT

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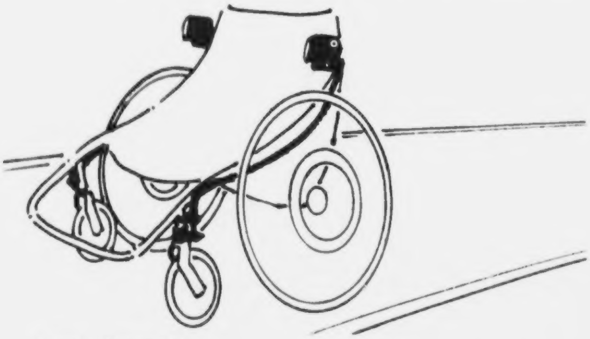
REFERENCES

1. Shapcott, Nigel, Abel, E.W., Hughes, S., "Aspects of Wheelchair Performance", Unpublished Report for Scottish Home and Health Department, (R/LIM/14/86) Aug., 1981.
2. Harris, A.I., Handicapped and Impaired in Great Britain, Part 1, with Cox, E. and Smith, C.R.W., Office of Population Censuses and Surveys. Social Survey Division, HMSO, London, 1971.
3. Jarvis, S.N., The Handicaps and Ergonomics of Children Who Use Wheelchairs. Ph.D. Thesis, University of London, 1978.
4. Fenwick, D., Wheelchairs and Their Users. Office of Population Census and Surveys, Social Survey Division, HMSO, London, 1977.
5. McLaurin, C.A., Brubaker, C.E., Bruning, E., Wood, J., Wheelchair Mobility - A Summary of Activities at the University of Virginia - Rehabilitation Engineering Center, 1976-1981.
6. Weber, R.A., Heckathorne, C.W., Rombola, G., Childress, D.S., Azimuthal Control for a Powered Wheelchair. Procedures of the International Conference on Rehabilitation Engineering, Toronto 1980.
7. Nelson, W.R., U.S.A. Patent 2,578,828, Ambulatory Invalid Chair, December 18, 1957.
8. Hickman, A.D., and Hickman R.H., U.S.A. Patent 3,972,945, Motorized Walker, March 25, 1975.
9. Padjen, J.A., U.S.A. Patent 2,576,413, Wheelchair, November 27, 1951.
10. Nickels, H., West German Patent 2,709,618, 5/3/77.
11. Shapcott, Nigel, U.S.A. Patent 4,364,580 Steerable Wheelchair, December 21, 1982.
12. Murray, George - Personal Communications, 1982.



Nigel Shapcott
University of Tennessee
Rehabilitation Engineering Center
682 Court Avenue
Memphis, Tennessee 38163

POWERED ULTRALIGHTS AND THE DISABLED PILOT

Michael J. Heinrich, R.E. and Nigel Shapcott, R.E.

University of Tennessee Center for the Health Sciences
Rehabilitation Engineering Program
Memphis, Tennessee

INTRODUCTION

The dream of manned flight has lead progressively from the Wright Brothers early efforts to the ongoing development of bigger and more sophisticated aircraft. This trend has lead to impediments to aviation. High costs are associated with pilot training, plane rental, purchase, maintenance and operation, while the difficulties with medical certification and strigent regulations exclude much of our population from the use of aviation for recreation, especially individuals with disabilities.

However, in the past few years the conjunction of the hang glider with a small engine has brought about a new era in aviation. These new vehicles, termed ultralights, offer increasing opportunities for aviation as a recreational sport (1). Training cost is moderate, the cost of the aircraft is low in comparison to conventional planes, maintenance and operating cost are extremely low. Currently there are a minimum of regulations and restrictions in the use of ultralight vehicles.

FAR 103

Prior to October 4, 1982 the Federal Aviation Administration (FAA) required such lightweight recreational vehicles to be foot launchable. Aircraft which could not demonstrate foot launch capabilities required FAA certification and registration as conventional or experimental aircraft, with associated regulations. The publication of Federal Aviation Regulation Part 103 on October 4, 1982 has brought the dawn of an exciting new era in recreational aviation with unprecedented opportunity for disabled aviators (2).

This date mav well rank in importance with September 19, 1944, when Alvenna Williams, a seventeen year old female bilateral lower extremity amputee, won a precedent setting court decision (Alvenna Williams v.s. The United States of America) which allowed her to proceed with solo pilot training despite her age, sex, and disabilty (3).

The Federal Aviation Administration views that it is desirable to maintain a minimum of regulations consistent with the safe operation of Ultralight aircraft to protect the general public, recognizing that participants in ultralight aviation are engaged in a sport, the risk of which does not effect others not directly involved in the activity.

FAR 103 Sub-part A defines an ultralight vehicle as one that is used and intended to be used for manned operation in the air by a single occupant. It is limited to recreational and sport purposes only, is not certified, has a weight of under 150 pounds for non-powered vehicles, and under 254 pounds for powered vehicles. This weight limitation excludes floats and safety devices. Powered ultralight vehicles are limited to five U.S. gallons of fuel, are designed to never exceed a speed of 55 knots, and are required to have a stall speed not in excess of 24 knots.

Sub-part B specifies certain operating rules which are primarily intended to insure that no person may operate an ultralight vehicle in a manner that creates a hazard to other persons or property.

In promulgating FAR 103 it is the position of the Federal Aviation Administration that further regulations will be forthcoming if the ultralight community itself does not initiate self regulatory procedures to ensure the safety of airspace and other persons or property. This self regulation is an opportunity for the disabled pilot to participate in regulatory procedures that ensure disabled individuals continued access to the skies for sport and recreational activities.

TENNESSEE AIR COOPERATIVE

In Memphis, an interest in recreational aviation has brought about the formation the Tennessee Air Cooperative. Through a grassroots effort, the individuals of the Tennessee Air Cooperative (T.A.C.) have banded together and established a non-profit organization to promote aviation for the disabled. This cooperative effort offers several advantages:

1. Economics - a group of individuals share expenses associated with purchase, operation, and maintenance of the plane; pilot training and certification as required.
2. Integrated sport - aviation is an integrated sport and as such can promote in the general public an awareness of the abilities of disabled individuals and thus is a vehicle for social and political change.
3. Voice and Visibility - This cooperative effort is providing a platform from which to participate in the self regulatory activities of the ultralight community with a strong voice and a visibility that will assist in protecting access to the skies for the disabled pilot.

In the fall of 1981, the Tennessee Air Cooperative came to life as an idea of Gary Kessler, a new arrival in Memphis and an employee of Lee's Orthopaedic Appliances. Gary, an active sailor, had found that sailing opportunities in the Memphis area were limited and sought other sport and recreational activities to replace his past sailing activities. The concept of the cooperative use of ultralights as a recreational sport, not only for himself but for his disabled friends, became the focus of a group of individuals interested in recreational aviation. The establishment and growth of this organization was a gradual process. While the concept of recreational aviation was an exciting idea, the lack of formal organization, facilities, and aircraft made it difficult to maintain active participation and interest. This group grew and collectively learned more about aviation in general, and in particular about powered ultralight aviation. Since the members of the air cooperative differed widely in disability classification and level of physical functioning, it was necessary to develop selection criteria for an aircraft that would meet the needs of the majority of the air cooperative members while requiring a minimum of modification to this commercially available aircraft.

SELECTION CRITERIA

1. The flat terrain around Memphis requires a powered aircraft.
2. The aircraft must be easy to fly with controls that would require a minimum of upper extremity function, and no lower extremity function.
3. Robust construction to ensure safety and durability.
4. Stability and handling characteristics while in flight.
5. Stall resistence.
6. An air frame with roll cage construction to improve safety in crash situations.
7. Air frame, power plant, and control construction which facilitates preflight safety checks from a wheelchair.
8. Air frame construction which facilitates transfer to and from the vehicle.
9. Air frame construction, control location, and seat construction which allows the use of specialized seating and positioning techniques and devices as required by the individual pilot.
10. Local dealer support for pilot training, construction, maintenance and repair of the aircraft.
11. A dependable power plant.
12. Car top portability.
13. Expectation that the selected aircraft would remain classified as a powered ultralight and therefore have minimum regulations and restrictions in operation (at the time of purchase in the Summer of 1982, FAR 103 had not been published).
14. Acceptable cost.
15. Sufficient payload capacity for safety devices and a lightweight wheelchair.

Utilizing these selection criteria, a wide range of powered ultralight vehicles were considered, and the Pterodactyl Ascender was chosen as the commercial ultralight most suitable for this cooperative venture.

The Pterodactyl Ascender is a tailless, high-wing, cable-braced design with a canard for pitch control and wing-tip rudders for control in the roll axis. With a pusher prop, powered by a two-cylinder, two-stroke, 30-hp Cuyuna engine, it has a reputation as a high-performance ultralight capable of steep climb-outs and high speeds (4).

DEVELOPMENT AND ORGANIZATION

Phil Vance, the local Pterodactyl dealer, proved most receptive to the concept of cooperative ownership of ultralight vehicles to promote

aviation for disabled pilots. While the process for chartering the Tennessee Air Cooperative as a non-profit cooperation had been initiated, the club members recognized that it was necessary to immediately proceed with financial commitment in the purchase of a plane in order to maintain interest and stimulate further participation.

While no single individual in the air cooperative had the financial means and credit to proceed with purchase of a plane, the group cosigned for a loan, and thus was able to initiate the purchase of the chosen aircraft. Lee's Ace Van Conversions of Memphis offered a physical location in their shop for the construction and assembly of the kit supplied aircraft. Construction of the aircraft by club members proceeded with guidance from the local dealer.

During the construction stage for this aircraft, which took approximately 70 man hours, Phil Vance worked with a local turf strip airport to ensure acceptance of T.A.C. by the airport management and availability of the airport for training and flights.

The Pterodactyl Ascender proved quite suitable as an aircraft for pilots with only upper extremity function, since it requires only joystick control by the right hand and throttle and kill switch operation from the left. However, certain additions and modifications to the plane were required to increase the independence of the disabled pilot during training activities and ground maneuvers. The addition of a nosewheel with remote steering, caliper brakes, repositioning of the starter rope and various seat modifications were accomplished without any change to the flight controls or control surfaces. Phil Vance, who is certified by AOPA as an ultralight instructor, is assisting with the training and instruction of the Tennessee Air Cooperative Student Pilots. Additionally, Phil is training several members of the air cooperative as bonified ultralight instructors within AOPA guidelines.

CURRENT STATUS

In December, 1982 the Tennessee Air Cooperative received its charter from the state of Tennessee as a non-profit cooperation to promote aviation for disabled individuals. The T.A.C. has now initiated requests to achieve Federal Tax exempt status. This January, the high level of training activity at the Isle-A-Port airport has generated considerable interest, and membership should reach 15 members by mid March.

This membership level will be maintained until the waiting list grows to a level that will allow additional aircraft to be acquired.

ACKNOWLEDGEMENTS

Training Support
Mid-South Ultralights and Gliders, 362 Washington Avenue, Memphis, Tennessee 38105.

Assembly Facilities
Lee's Ace Van Conversions, 1166 Monroe Avenue, Memphis, Tennessee 38163.

Legal Assistance
John Parker, Attorney-at-Law.

Training Facilities
Isle-A-Port Airport, Presidents Island, Memphis, Tennessee 38143.

Members
Tennessee Air Cooperative, 4209 Camelot Avenue, Memphis, Tennessee 38118.

REFERENCES

1. Markowski, Michael A., Ultralight Airplanes, Scientific American, July, 1982.

2. Special Gilder Rider Bulletin: FAR 103, Glider Rider, September, 1982.

3. Smith, Kenneth W., Flying Beyond the Handicap, AOPA Pilot, October, 1982, pp 68 - 73.

4. Pterodactyl, Ltd., Watsonville, California.

training at Isle-A-Port

Michael Heinrich
University of Tennessee
Rehabilitation Engineering Center
682 Court Avenue
Memphis, Tennessee 38163

THE PTERODACTYL ASCENDER - MODIFICATION FOR AND PREFLIGHT BY THE DISABLED PILOT

Michael J. Heinrich, R.E. and Nigel Shapcott, R.E.

University of Tennessee Center for the Health Sciences
Rehabilitation Engineering Program
Memphis, Tennessee

INTRODUCTION

The Tennessee Air Cooperative, a non-profit cooperation to promote aviation for the disabled, has chosen the use of the Pterodactyl Ascender as the club aircraft. Selection criteria for this decision have been described elsewhere in this publication (1).

The Federal Aviation Administration (through Federal Aviation Regulation Part 103) has established rules and regulations which affect the operation of ultralight vehicles. This rule does not require airmen/aircraft certification or vehicle registration and is premised on the absolute minimum regulation necessary to ensure air and public safety. However, the FAA notes the burgeoning growth of the ultralight population will necessitate further regulation, if adequate self regulation by ultralight users and industry is not forthcoming. It must be emphasized that the individual ultralight operators support of and compliance with national self regulation programs is essential to the FAA's continued policy of allowing industry self regulation in these areas. The Tennessee Air Cooperative supports the self regulation concept, and is actively participating with the ultralight community in such self regulatory activities to ensure continued access to the skies by disabled pilots.

A part of such activities is the development of a rigorous training program for student pilots. Simple, functional, and reliable modifications to the club aircraft facilitate such training activities and increase independence in operation of the aircraft during and subsequent to the formal training period.

THE AIRCRAFT

The Pterodactyl Ascender is well suited to the members of the club. From take off to landing it requires only a minimum of upper extremity function in order to fly the aircraft, since there are no foot operated controls. The flight controls for this aircraft consist of a joystick, which is normally mounted for right upper extremity operation. Movement of this joy stick in an anterior posterior plane controls the pitch (nose up and nose down) of the aircraft. Lateral motion of the joy stick controls yaw (right and left turns). The lateral motion of the joystick control operates winglets which operate as separate rudders by inducing drag and spoiling the lift over the respective wing. This lowers the air speed of that wing which reduces lift, banking the aircraft in the direction of the turn. On the left, a simple throttle lever controls engine speed. Immediately adjacent to this lever is the kill switch. Thus once trained, a disabled pilot with reasonable upper extremity function can fully operate and control this aircraft with virtually the same abilities as that of the non-disabled pilot.

The name Pterodactyl seems well suited for this creature which once airborn engages in graceful soaring flight while on the ground is somewhat of a lumbering dinasour. With the conventional aircraft the pilot uses the heels of his/her boots for braking action, and when below the speed at which aerodynamic controls can be used for steering (about 12 MPH), must utilize the lower extremities for turning the plane by lifting the nosewheel and moving it laterally to change direction. Therefore, it was necessary to address the difficulties of ground handling the aircraft in order to facilitate training activities. This training involves long hours of runway training, taxiing on the ground, gradually and progressively increasing speed and altitude.

MODIFICATIONS

A number of modifications were undertaken to the conventional aircraft. A steerable nosewheel which requires lower extremity function is a commercially available option. This steerable nosewheel, in conjunction with a caliper brake (adapted for addition to this nosewheel, activitated by a conventional bicycle brake lever mounted to the joystick control) provides braking abilities for pilots with diminished lower extremity function. A fairly simple addition to the nosewheel structure has allowed steering of the nosewheel by the upper extremities through a cable, pulley and lever system, analogous to wagon tongue steering. This system has been mounted in such a manner that it does not detract from the controlability of the nosewheel for those pilots who have lower extremity function.

The commercial seat for this aircraft is an amazingly simple sling design that evolved during the initial development of this plane, when weight-shift was used to control pitch. While the basic structure of this commercially provided sling seat was maintained, the addition of a slip over cover using velcro closures provided for additional lateral support to the pelvis and trunk. Posterior support in the form of a headrest for the head and neck was also added. The seat modifications also include saddlebags that allow the inclusion of an emergency kit along with CB-walkie-talkies which assist with communication with the instructor if some difficulty in operation causes the plane to become inoperable by the student pilot some distance away. This seating was maintained in a relatively low position relative to the main components in the airframe. This provided additional lateral stability, however, this low position in the aircraft required an extension of the pull starter rope to facilitate reach. Current FAR's allow the operation of ultralights in daylight hours only between official sunrise and sunset. However, with the addition of a safety light, current FAR's allow operation of the ultralight vehicle for one half hour prior to sunrise and one half hour after official sunset. Since it is these hours of the day that most often have the most suitable low wind conditions for operation of this ultralight vehicle, and since the ongoing operation of a strobe unit during daylight hours provide additional visibility for safety, this was deemed a necessary addition to the club plane. A commercial strobe kit was purchased and assembled by club members.

PREFLIGHT

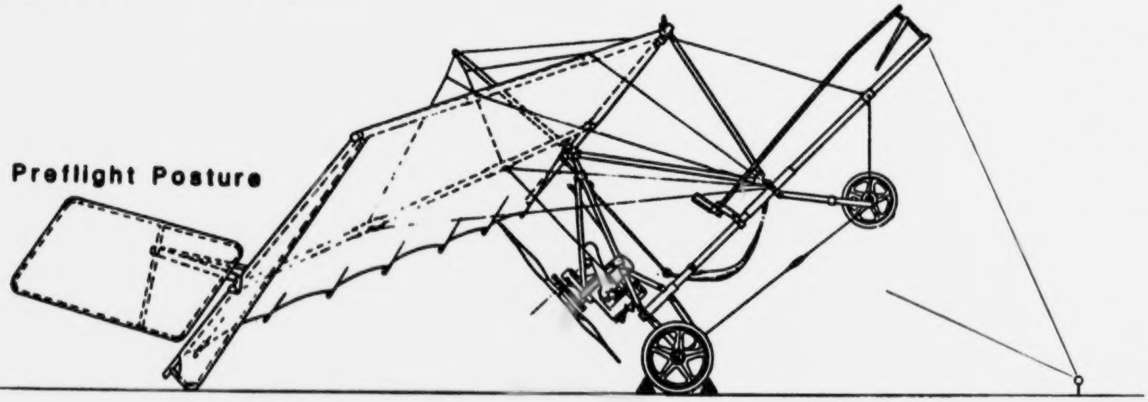
These modifications, along with techniques of preflight developed by the club members, allow relatively independent operation of this aircraft. A preflight inspection is an important part of flying any aircraft. However, for an ultralight a preflight inspection is mandatory every time it is flown after it has been dismantled and reassembled. The Tennessee Air Cooperative mandates a preflight inspection every time the aircraft is operated.

A thorough preflight consists of carefully inspecting each element of the flying ensemble. These elements are:

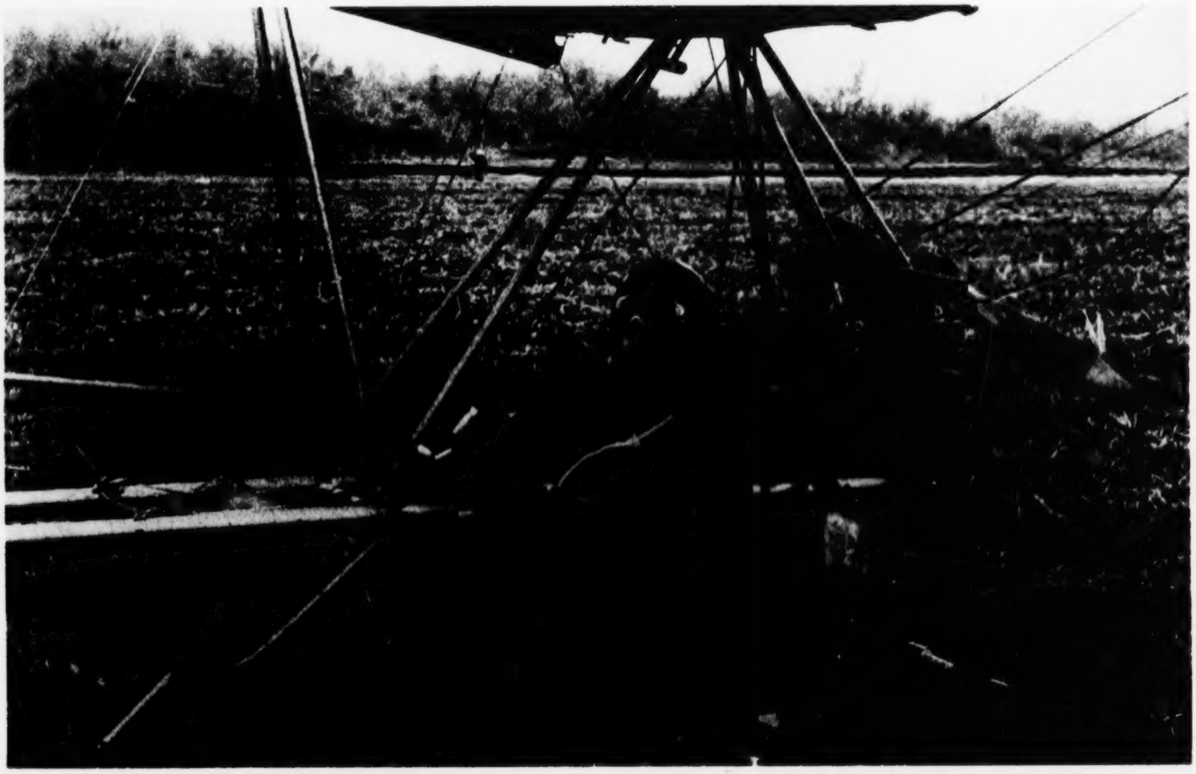
1. Nuts, bolts and fittings,
2. Cables and struts,
3. Tubing or Airframe,
4. Fabric or covering,
5. Seat and harness assembly,
6. Control surface operation and fastenings,
7. Visual check of whole aircraft for distortions in tubes, etc.
8. Power plant and prop,
9. Landing gear, steering,
10. Wing compression struts,
11. Fuel level and supply tubing.

WHEELCHAIR TECHNIQUE

The size and structure of the Pterodactyl Ascender in its conventional orientation on the ground prohibits adequate preflight inspection from a wheelchair. Structures immediately



PTERODACTYL ASCENDER



below, within and above the wing surfaces are not reachable from the seated posture. However, the construction of the Pterodactyl Ascender is such that a change in its normal orientation by lifting the nosewheel and allowing the aircraft to assume a nose up position, resting on the wing tips and main landing gear (rear wheels) will allow access to the top surface of the wing, king post, wing support wires as well as access to the interior of the wing (compression struts and other internal structures) from a wheelchair. Placing this aircraft in the nose up position and returning it to its normal ground attitude can be accomplished by an individual with only moderate strength. The main landing gear must be chocked to prevent forward motion. A lead rope, tied to the anterior portion of the airframe and passed through a loop in the tie-down stake, is utilized to convert the upward pull of the nose in the rearward position to a downward pull. This assists the wheelchair pilot in safely maneuvering the plane. In essence, the nosewheel and canard surface of the airframe is lifted against the resistence of gravity until the center of gravity of the aircraft shifts from forward of the rear axle to behind the rear axle. With this shift of the center of gravity of the aircraft, it becomes necessary (rather than providing a lifting force to the forward position of the airplane) to exert a downward force to keep the plane from falling backwards onto the wingtips and possibly causing damage. It is to this effect that the rope has been attached to the forward part of the airframe and passed through the tie-down stake. By gradually letting out additional rope the Pterodactyl Ascender can be gracefully lowered onto its wingtips and preflight inspection can proceed. Once preflight inspection has been accomplished (occasionally with the assistance of a hand held mirror to gain additional view of the interior of the wings) the plane can be returned to its normal position by reversing the procedure. The tie-down cable is pulled to begin to bring the nose of the aircraft down, but caution must be taken so that when the center of gravity passes forward of the rear axles that the pilot is in a position to take the weight of the plane and lower it gradually to the ground.

ACKNOWLEDGEMENTS

Members
Tennessee Air Cooperative, 4209 Camelot Avenue, Memphis, Tennessee 38118.

REFERENCES

1. Heinrich, M., Shapcott, N., Powered Ultralights and the Disabled Pilot. Proceedings of the Sixth Annual Conference on Rehabilitation Engineering, San Diego, California, 1983.

Michael Heinrich
University of Tennessee
Rehabilitation Engineering Center
682 Court Avenue
Memphis, Tennessee 38163

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A MULTI-PURPOSE RECREATIONAL VEHICLE FOR THE DISABLED

Nigel Shapcott, R.E. and Michael Heinrich, R.E.

University of Tennessee Center for the Health Sciences
Rehabilitation Engineering Program - Memphis Campus

INTRODUCTION

It has become widely established in Rehabilitation facilities throughout the world that recreational activities are an important part of a comprehensive rehabilitation program.

Stoke Mandeville Hospital in Great Britain pioneered the concepts of wheelchair sports and the Wheelchair Olympics, and there are now thousands of wheelchair athletics participating in many different types of sports; such as, discus, javelin, table tennis, basketball, archery and track events.

Other types of recreational activities; such as, horticulture have been established at the Nuffield Foundation in Great Britain, as being of benefit in the rehabilitation process.

Once discharged from their rehabilitation facilities, individuals are encouraged to continue to participate in various types of recreational pursuits and, of course, to return to employment where possible. A splendid example of this was illustrated on the front cover of a recent British publication (1). A full page color picture shows a farmer on his farm tending fields from a Honda three-wheeled all terrain cycle. The farmer has double above knee amputation.

In Scotland Alan Haddow, who has a C-6 spinal cord lesion, has adapted a similar vehicle for "walking" in the beautiful Scottish hills (2). Alan has bought a second A.T.C. in order that his companion may keep pace with him.

CURRENT TRENDS

In the U.S.A. there is a considerable difference in the way people live compared to the rest of the world. Here it is not uncommon for people to have a weekend farm which is a combination recreational/vocational/tax write-off and overall satisfying operation.

In Memphis, a novel method of farming for disabled people is being pioneered as such a recreational activity. The Tennessee Air Cooperative and the University of Tennessee Rehabilitation Engineering Center have conducted limited trials to establish the feasibility of novel vehicles adapted for the disabled used for weekend agricultural activities.

The vehicle chosen for these trials was a Pteradactyl Ascender ultralight. A powered ultralight, as defined by the Federal Aviation Authority, is a vehicle capable of flight weighing not more than 254 pounds, incapable of flight over 55 knots (63.25 mph), a stall speed of not more than 24 knots (27.65 mph), and a maximum fuel capacity of 5 U.S. gallons, and designed for single occupancy (3).

CONTROL CONFIGURATION

This particular vehicle was chosen for it's rugged reliability, short take-off and landing capability and simple control configurations. Figure (1) shows a silhouette of the vehicle. Elsewhere in this publication are further details on the aircraft. The basic flight control system (a, fig.3) does not require use of the lower extremities and the steering for ground use can be simply modified to be operated by hand (b, fig.3). The hand operated throttle and ignition cut-off are operated by the left hand (c, fig. 2).

COST EFFECTIVE FARMING METHODS BY MULTI-USE VEHICLES

The Pteradactyl uses about $2.00 of gas per hour and is, therefore, an extremely cost effective vehicle. The way in which it can be utilized in farming are listed below. The vehicle cannot be used commercially as per FAR 103 (3), but can be used for the purposes listed below if it is not being hired to do so.

General Farm Management Tool

Survey of
- fences
- crops
- pasture land
- farm animals
- irrigation/drainage planning
- general transportation

Aerial Farming Techniques

- crop spraying
- aerial seeding
- aerial fertilizing
- retrieving lost animals
- herding

Surface Farming Techniques

- ploughing
- seeding
- light earth moving; i.e., irrigation channels

OPERATION AS A FARMING TOOL

Referring to figures 1, 2, and 3;

- fig. 1 shows the aircraft in the low level crop spraying configuration.
- fig. 2 shows the aircraft using it's powerful 30 hp motor to drive it in the ground configuration. In this picture the vehicle is being used for bean field ploughing.
- fig. 3 shows the aircraft in another ground use configuration, in this case seeding of a bean field. A high shutter speed was used for this picture "freezing" the propeller.

figure 1

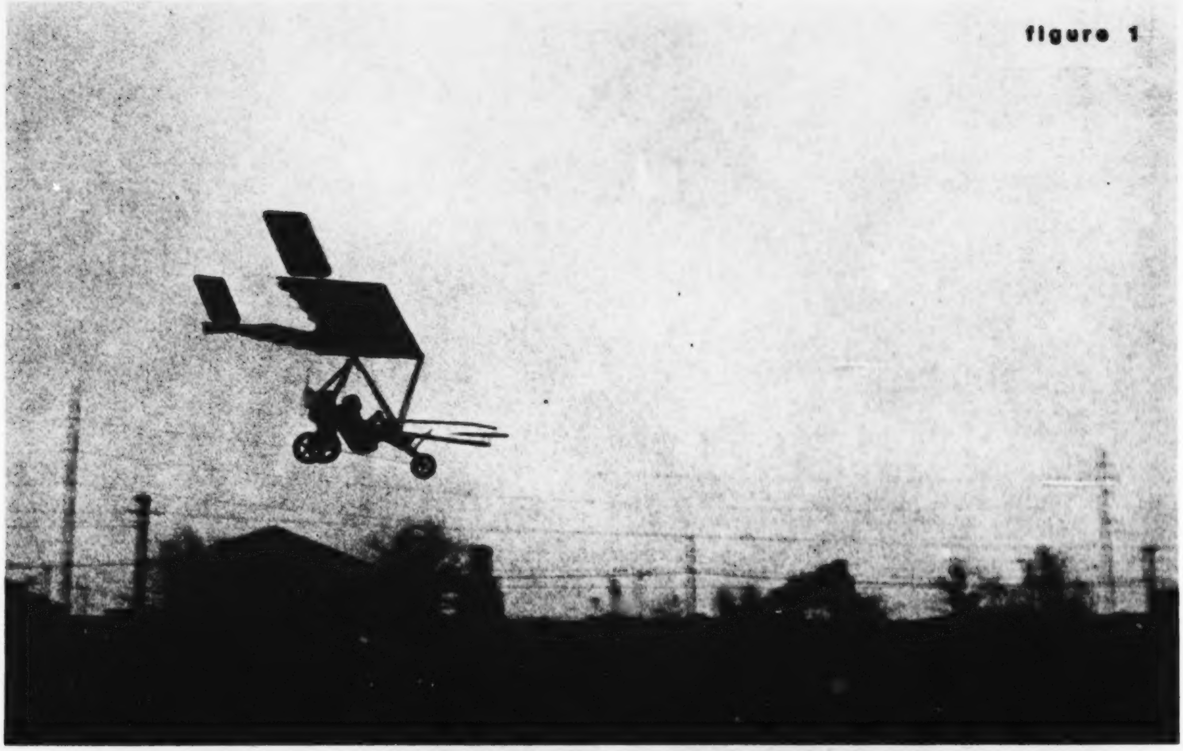

figure 2

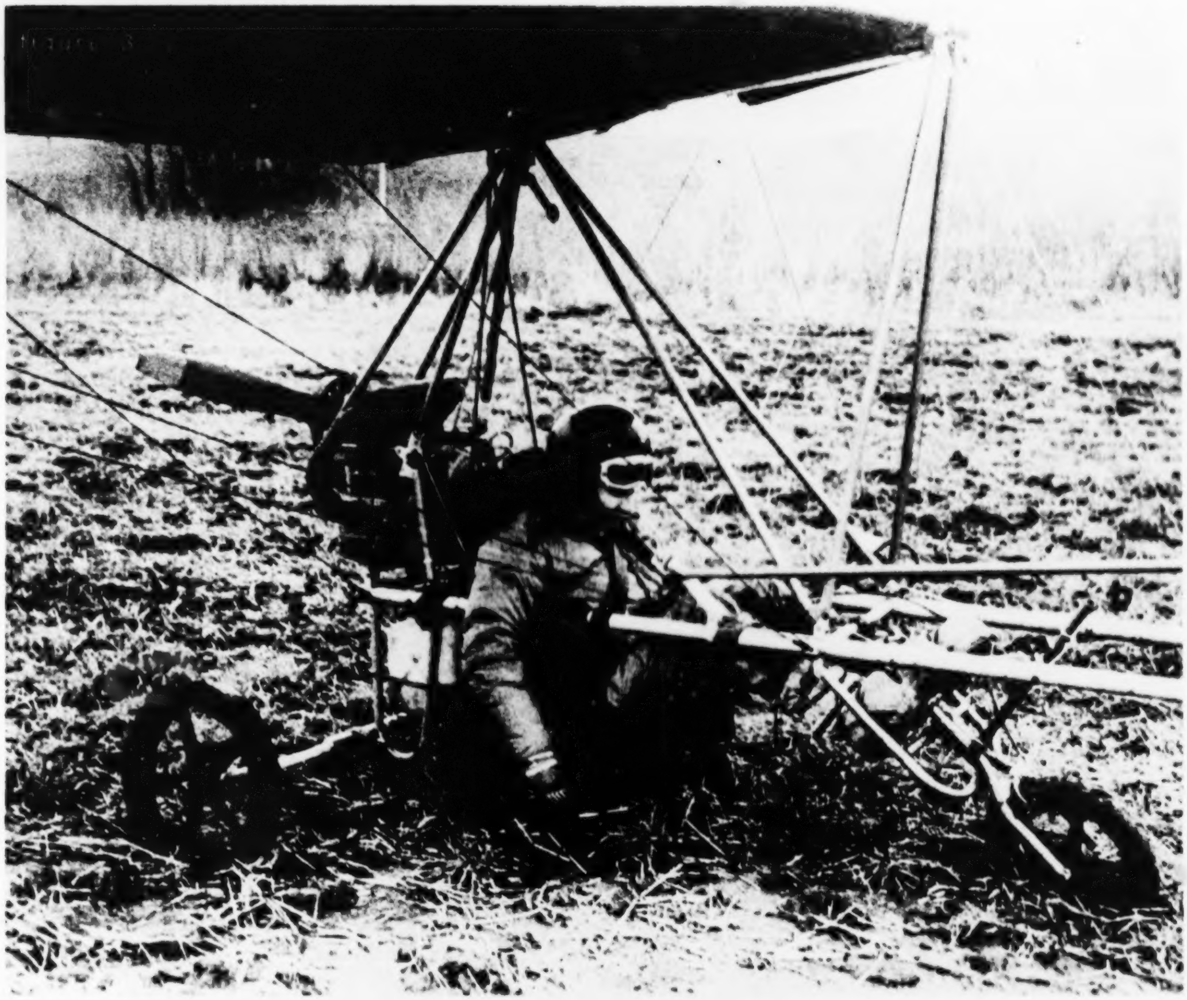

Figure 3

CONCLUSIONS

Judging from the enthusiastic response of our disabled participant, this venture is worth pursuing. Later on in the year experience will be gained with the use of floats on this aircraft, which will enable ready access to remote lakes for fishing activities, etc.

Minor modifications will be made to the front wheel to prevent penetration beyond the axle during ploughing operations.

ACKNOWLEDGEMENTS

Beneficial Designs - Field Test
Tennessee Air Cooperative - Pteradactyl Ascender
Mr. Jones - farmer

REFERENCES

(1) Handicapped Living, July 1982 issue, West Street, Epsom, Surrey, England.
(2) Alan Haddow, personal communications, January 1983.
(3) F.A.R. 103, A and B, October 4, 1982.

Nigel Shapcott
University of Tennessee
Rehabilitation Engineering Center
682 Court Avenue
Memphis, TN 38163

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THE DEVELOPMENT AND IMPLEMENTATION OF GUIDELINES FOR DESIGN DEVELOPMENT PROPOSALS

PETER W. AXELSON, M.S.M.E.
LYNN R. PHILLIPS, TRF RESEARCH DIRECTOR
LARRY J. LEIFER Ph.D.

PARALYZED VETERANS OF AMERICA
TECHNOLOGY RESEARCH FOUNDATION (TRF)

ABSTRACT

This article discusses a solution to a problem that was identified in a small group session at the American Association for the Advancement of Science (AAAS) Conference on Technology and Handicapped People (29 and 30 September 1982).

It has been observed that rehabilitation problem solvers typically apply existing technologies to solve problems for the disabled. However, the application of existing technologies toward the development of devices and systems for people with disabilities is not basic research. Unfortunately, funding agencies which are trying to assist in the development of devices, systems and methodologies do not have the mechanisms for dealing with proposals which are not research oriented. The need for design development proposal guidelines has thus become apparent. This paper will discuss a set of design proposal guidelines as they were developed for the Paralyzed Veterans of America Technology Research Foundation. Prior to discussion of the guidelines, the reasons for "proposals" and proposal guidelines will be discussed to facilitate an understanding for a new design development proposal format.

PURPOSE OF PROPOSALS

Proposals submitted to agencies are the sole basis for making funding decisions. The main body of any successful proposal must communicate all of the information regarding the work to be performed. Pictures, graphs and charts, when used in the body of the text are useful to enhance the document. The researcher or designer will have to keep in mind that their attitude comes through when the proposal is reviewed. The process of preparing a proposal requires the researcher or designer to refine his or her hypothesis, research methodology, evaluation protocal etc., to the extent that the information can be communicated in a clear manner to decision makers.

PURPOSE OF PROPOSAL GUIDELINES

Guidelines for the review of submitted proposals generally are based on the guidelines for the proposal itself. Therefore, proposals submitted to a funding source must be consistant in format for purposes of fair and just review. The researcher or designer must not underestimate the importance of following the guidelines when writing a proposal.

The funding agency should understand the signifigance of their guidelines for submission of solicited proposals. The required format will have a significant effect on the framework within which the researcher or designer will formulate his or her plan of action.

Well designed guidelines should help the researcher or designer to refine his or her hypothesis, methodology, design criteria etc. Appropriate guidelines will most often reflect the attitude and priorities of the funding agency and they will guide the researcher or designer to a more sucessful research conclusion or end product.

REHABILITATION RESEARCH AND DEVELOPMENT FUNDING REQUIREMENTS

There appear to be four general categories of funding requirements in the field of rehabilitation research and development;

- Program
- Basic Research
- Applied Research
- Device and System Development

Most funding agencies are familiar with basic research proposals. As might be expected, the guidelines for solicited proposals from most funding agencies best fit the basic research template. Some agencies have proposal guidelines which take into consideration the characteristics of program funding requests and applied research. Until now, no rehabilitation funding sources have had guidelines written for the device or system development proposal.

PROBLEMS WITH RESEARCH PROPOSAL GUIDELINES

As previously mentioned, most agencies funding research and development in the field of rehabilitation have proposal guidelines which provide a good framework for basic and many types of applied research. However, potential device and system development does not fit into research proposal guidelines. Designers of systems and devices for persons with disabilities have difficulty in communicating their development plan in a research proposal format. When a proposal for device or system development is received by the funding agency, it is difficult to review when written in the framework of a research proposal. Review guidelines are designed to assist other researchers in appraising the proposed research hypothesis, methodology, budget etc. Under these circumstances the design development proposal can not be appraised fairly in comparison to a research proposal, especially when it does not look like a research proposal.

MISSING INGREDIENTS

The research proposal format does not contain the following elements which are essential in determining the feasability of a given device or system development proposal:

- A Specific Definition of the Need;
- A Specific Definition of the Problem;
- Design Specifications;
- Design Alternatives;
- Objective Evaluation Protocal;
- Interaction with Manufacturers;

ORGANIZATION OF THE DESIGN DEVELOPMENT PROPOSAL

The use of similar design development guidelines has been proven to work well within the Product Design Program at Stanford University in California. One such project which made use of design development guidelines was the development of the ARROYA downhill skiing system for persons with disabilities (now a commercially available device). Here are the guidelines as the Paralyzed Veterans of America Technology Research Foundation (PVA TRF) will be using them:

THE DESIGN DEVELOPMENT PLAN

(a) Write a summary statement of the proposed Design Development Project. Explain in layman's language to assist the trustees in their evaluation of this proposal.

(b) The Need

(1) Global

What relevance does the proposed design development project have in benefitting those persons who are severely disabled by injury or disease to the central nervous system? This statement should be very short and brief.

NOTE - Most proposals tend to dwell on justification of the need from a global perspective. Since the PVA TRF was founded in response to the global need for research, and device and system development for persons with disablities, it is not necessary to dwell on the justification of the need from a global perspective.

(2) Specific

What specific need exists that calls for funding of this design development project? Why is this need of importance in relation to the perspective of an overall rehabilitation program? Identify the size of the population group to benefit from your work.

NOTE - The documentation of a specific need is important as it is necessary to justify the funding of one project in relation to other design development projects.

(c) Problem Definition

In relation to the specific need, what is or are the specific barriers which bring about the existence of the need? Identify the problem or problems that the proposed design development proposal intends to deal with.

(d) Design Specifications

Specific design criteria must be established to solve the identified problems with regard to dimensional and performance specifications, maintenance requirements, cost to the consumer and manufacturability. Each design specification, almost without exception, should have a numerical value attached to it. As a rule, for a given project there are ten to twenty design specifications to which numerical values can be attached.

(e) Design Alternatives

Several (at least three) design alternatives, which vary in principle to one another, should be proposed. Drawings should support each design alternative. If three dimensional modeling is performed, a photograph of the model or models may be included. The positive and negative aspects of each of the design alternatives should be explained in relation to the design specifications put forth in Section (d). The chosen design alternative should be identified. The motivation for selection of the chosen design alternative should be included. A decision assessment matrix is suggested:

DESIGN ALTERNATIVES

A	B	C		
°	°	°	1	FACTOR
°	°	°	2	
°	°	°	3	

(f) State of the Art Review

What technologies are currently available that will be used in the proposed design alternative? If the technologies exist in commercially available devices they should be documented visually and verbally with respect to cost and availability. In addition, a minimum of two letters of support from potential manufacturers should accompany this section of the proposal. If the proposed technologies are not commercially available, the availability and practicality of utilizing the proposed technologies should be documented.

(g) Methodology

Outline the tasks (10 - 20) necessary to complete the proposed design development project. In particular the proposal should address the protocol for evaluating the project. The evaluation protocol should explain how function, durability, ease of use, safety, reliability and maintenance of the device will be assessed. The design team should describe how they will involve users and manufacturers in the evaluation process. Protocol should be outlined for the training of service delivery personnel and the users of the device.

(h) Time Matrix

Design development projects typically do not follow a linear time scale. Granted, certain tasks can not begin until others are completed; however, many can occur simultaneously. Milestones in the design process should be identified by date. Possible blockage points that could inhibit the progress of the project should be identified. Points in the schedule where decisions must be made should be noted. Contingencies and alternatives should be suggested where decision modes exist.

(i) Resources

Personnel, work and testing facilities, equipment and any other resources necessary for the completion of the proposed work should be documented in this section of the proposal.

(j) Budget

Support documentation should be given for equipment expenditures. The agency or design team proposing the project is expected to match funds on all major equipment expenditures. Prepare a comprehensive budget. Where the project incurs real expenses that are not to be borne by this proposal, indicate the anticipated expense and note that it is available at no charge.

REVIEW GUIDELINES FOR THE DESIGN DEVELOPMENT PROPOSAL

Listed below are the guidelines which have been developed to assist researchers in objectively and subjectively responding to all relevant aspects of the design development proposal:

Technology Research Foundation
Paralyzed Veterans of America
801 18th Street
Washington, D.C. 20006
(202) 872-1300

Proposal No:

Title:

Design Team/Institution:

Reviewer:

I. Relevance to Spinal Cord Injury?
How relevant is the proposed research to spinal cord injury?

II. Rationale for the Proposed Research.
Please assess the designer's perception of the problem or problems.

III. Design Specifications
Are the design specifications objective and measurable? Are they realistic? Please explain.

IV. Design Alternatives
Please assess the validity of the proposed design alternative.

V. Knowledge of Pertinent Work
Is the investigator familiar with similar devices and technologies used in other devices?

VI. Feasability Demonstration
Has the proposed design alternative been proven experimentally? Can it be done?

VII. Methodology
Is the proposed methodology in line with the goals and objectives? Is the methodology appropriate for this kind of project? If not, how could it be improved?

VIII. Qualifications of the Principle Investigator and Research Team
Are the designers qualified to do the proposed work? What particular strength/weaknesses do the applicants have?

IX. Proposed Calendar
Does the investigator leave adequate time to accomplish the project? If the proposal is a multiyear project will completition of subsequent years yield substantive results? If not, what changes would you recommend?

X. Budget
Are the budget items appropriate? Which budget items could be adjusted, if any? Why?

XI. Other Comments

CHOOSING THE APPROPRIATE GUIDELINES

The researcher or designer must be able to determine which guidelines are most appropriate for the research or development which he or she is proposing to do. If the proposed work involves the development of a physical piece of hardware or computer software the design development guidelines will be more appropriate than research guidelines for writing up the proposal. Almost as a rule, if design criteria can be determined for the project, the design development guidelines should be used. Using the most appropriate guidelines will give the project investigators a better chance of communicating the proposed research or development project.

CONCLUSION

The implementation of design development guidelines will enhance the PVA TRF's mechanism for making knowledgeable funding decisions with regard to the development of devices and systems for persons with disabilities.

The Veterans Administration's Rehabilitation Research and Development Service is examining their merit review proposal guidelines and hopefully will create a template that will facilitate better, the review of device and system development proposals.

15.1

SELECTED FUNDING ISSUES IN REHABILITATION ENGINEERING SERVICE DELIVERY

Rick N. Holte, M.Sc.
Rehabilitation Engineering Center
Children's Hospital at Stanford

ABSTRACT

This paper discusses some business aspects of rehabilitation engineering service delivery. Three funding problems and their implications are described. Secondly, service delivery cost areas are analyzed. Three courses of action are proposed in the concluding section.

INTRODUCTION

Recently, delivery of rehabilitation engineering services has become a topic of interest. At last year's RESNA Conference, an Ad-Hoc Committee was formed and half a dozen papers were given on the subject (1). At the root, the main concern is undeniably funding, for without money, there will be no services or delivery strategies. This paper will discuss some economic aspects of rehabilitation engineering service delivery, initially describing problems in receiving reimbursement, then analyzing the costs of delivering rehabilitation engineering services.

ACCOUNTS RECEIVABLE: GETTING PAID

Not An Insured Service

Frequently, one finds that third party insurers do not cover rehabilitation engineering services. Prosthetic and orthotic devices are covered more frequently than seating or communication devices or evaluative services. The implications of trying to deliver an uninsured service are therefore (1) you may not be compensated at all by the insurer; (2) you may have to submit a barrage of supportive letters, invoices, prescriptions, and chart notes to substantiate your claim; (3) you may not be able to deliver the service.

Underpayment

Even though prosthetic and orthotic devices are sometimes an insured service, the reimbursement might be very low. For example, MediCal (2) and Medicare (3) fee schedules for prostheses and orthoses cover only about 50-65% of the usual prices charged in the San Francisco Bay Area. What a heavy penalty! Then, either the device supplier must absorb a 40-50% loss on his services, or pass along to the patient the billing for same, if allowed. This will be a hardship in either case

Late Payment

The MediCal state health insurance has been under a good deal of pressure lately to provide more services at less cost. At times, it almost seems that they delay claims, in the hope that the faint-hearted or under-capitalized will give up, go away and/or provide the service for free. For example, the January 1983 "MediCal Update" provider bulletin said they would reject claims where the provider put a dash through the "cents" column instead of two zeroes for claims on even-dollar-value items (4).

We hope that delays are unintentional, and are simply the result of paperwork snafus. Regardless, the delay in receiving payment is a serious problem. The Children's Hospital at Stanford averages about 90 days in collection on all accounts receivable, a fantastic cost. Smaller providers, with less capitalization, cannot afford that credit squeeze and are probably forced into other lines of work. Certainly, some are forced to be selective about who they see.

Impact on the Patient

It is undeniable that the above-mentioned burdens on the supplier will adversely affect patient services. The patient may find that his friendly neighborhood wheelchair shop has gone bankrupt. He may find, particularly if he relies solely on state-supported insurance, that he has less than adequate coverage for rehabilitation engineering goods and services.

Effect on the Suppliers

This scenario of limited returns, impediments to collection, and probably a shrinking referral base, has definite effect on suppliers of rehabilitation engineering services. Around the San Francisco Bay Area, one hears of staff cutbacks in private prosthetic/orthotic facilities, and also at Children's Hospital at Stanford. Certainly, one must sharpen one's pencil to try and run more efficiently.

Another more insidious effect is the moral dilemma faced by persons providing rehabilitation engineering goods and services. I think it is fair to say that most of us in the field are motivated by more than the profit motive: we care about our clients, and about the quality of work we do on their behalf. How very difficult it is, then, to compromise one's standards of services, or outright deny services for the economic reasons outlined above.

ACCOUNTS PAYABLE: WHERE YOU SPEND IT

The Cost of Delivering Rehabilitation Engineering Services

There are some general characteristics of rehabilitation engineering which will tend to result in high costs per service unit. Basically, it deals with a low-incidence type of problem, eliminating high-volume cost reductions. Unlike nearly all manufactured products, the quality and quantity of rehabilitation engineering devices is often primarily related to the quality and quantity of work done by the individual provider. Thirdly, the multidisciplinary aspect of rehabilitation engineering is inherently costly. Finally, the system as a whole has an overhead originating with the third-party employees who adjudicate the authorization requests and provider payment claims.

In addition to these general, uncontrollable characteristics, there are several factors which contribute directly to the cost of rehabilitation engineering services, and over which some control can be exercised. These include labor-related costs factoring wages, benefits, and efficiency; materials and purchased services; and indirect costs from uncollectibles, support infrastructures, and overhead.

Labor Costs

This is a fairly straightforward topic, except for efficiency factoring. The basic labor cost is simply employee wages, plus benefits which will vary from 15-25% depending on the benefits offered. At Children's Hospital at Stanford, the benefits include health and dental coverage and a retirement plan, and they run at 18%

Gross working efficiency is billable hours divided by available working hours. Usually this figure diminishes as one progresses upwards in the departmental hierarchy, as the certified people and department heads will spend more time than technicians in activities such as telephone calls with doctors, therapists and patients, attendance at ward rounds, clinics, meetings and conferences, and so on. Departmental efficiency can be calculated from a work study.

While at the Rehabilitation Centre for Children in Winnipeg, Canada, the author occasionally monitored the work habits of the Special Devices Department staff. The approximate gross working efficiency for technicians was 85%, and 25% for shop foreman and assistant engineer. On the basis of billable versus total hours, the author's efficiency (as department head) was only 10%, because very little of his time was spent in actual fabrication. Needless to say, the other 90% was put to good use, but not in a directly billable manner.

Net efficiency should include the effects of holiday, sick and other leave time. At Children's Hospital at Stanford's Rehabilitation Engineering Center, this averages 14% of total available annual hours.

Material Costs

Direct costs for materials, purchased components, and professional services will vary depending on the type of service being delivered and the resources of the facility. The usual range seems to be 10% to 35% of list cost for materials' direct cost. The lower figure would be representative of devices fabricated entirely from raw materials, such as plywood-foam-vinyl inserts. The higher figure would be associated with equipment containing purchased components, such as an above-elbow prosthesis with elbow, wrist, and terminal device components (5).

Indirect Costs

Indirect costs cover a large number of infrastructure supports. They include cost of debt carry, uncollectible accounts, building rent and maintenance, secretarial support, insurance, property taxes, and so on. These are estimated to be on the order of 31% at Children's Hospital at Stanford's Rehabilitation Engineering Center, with 12% due to finance costs and 19% from administrative overhead.

Composite Cost

The graph below depicts the breakdown of costs according to the previous analysis for the last half of 1982 at the Rehabilitation Engineering Center of Children's Hospital at Stanford.

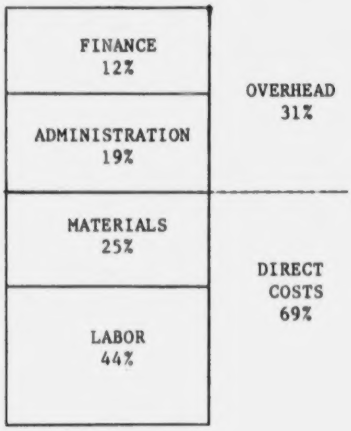

Figure 1. Breakdown of service costs at Rehabilitation Engineering Center, Children's Hospital at Stanford, July through December 1982.

THE BOTTOM LINE: OBSERVATIONS AND CONCLUSIONS

As with all disciplines within the medical field, rehabilitation engineering does have a financial aspect. From the previous discussion of expenses and reimbursements, it should be clear that there is need to facilitate greater availability of funding and to use more efficiently that funding which is available.

Promote Rehabilitation Engineering as Cost-Effective

One main objective of rehabilitation engineering is to enable greater independence of the service recipients. This should allow a cost-saving in other areas due to greater employment, less attendant care, decreased amount of medical intervention, and so on. Funders should know about these cost reductions. Bowe (6) states "The impact may be particularily strong on social security issues, but it will also be felt in other entitlement and discretionary programs".

Affect the Legislative Process

The patient should be informed honestly if his government health insurance is not providing complete coverage. Legislators will feel most compelled to improve public health insurance programs if their constituents tell them directly. The influence of providers on the political process is greatly compromised by the inherent conflict of interest. So, patients should make their needs known to their elected representatives.

Cost Control: Immediate and Long Range Costs

One of the purposes of the above discussion on the costs of rehabilitation engineering services is to point out that there are places for cost cutting. This starts with an awareness of the importance of such a venture, and includes attention to detail by everyone involved in the delivery of services. It is also incumbent on us as designers and recommenders of equipment to make careful choices about the durability and suitability of devices, so that dollars spent on rehabilitation engineering services are indeed well spent.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation for the fine efforts of his colleagues at Children's Hospital at Stanford, Rehabilitation Engineering Center.

REFERENCES

1) Proceedings of the 5th Annual Conference on Rehabilitation Engineering, Rehabilitation Engineering Society of North America, Houston, 1982.

2) MediCal Provider Manual for Allied Health Services. Computer Sciences Corporation, Sacramento, CA, 1982.

3) "Area Profiles for Orthotics and Prosthetics." Blue Shield of California, San Francisco, 1982.

4) "MediCal Update", Bulletin 45, January 1983. Computer Sciences Corporation, Sacramento, CA.

5) "Time Estimate Breakdown for Above-Elbow Prosthesis", Ontario Association of Prosthetists and Orthotists, Toronto, 1981.

6) Bowe, Frank. Rehabilitating America, Harper and Row, New York, 1980.

CORRESPONDENCE

All correspondence may be addressed to the author at:

Rehabilitation Engineering Center
Children's Hospital at Stanford
520 Willow Road
Palo Alto, CA 94304

FUNDING: THE BOTTOM LINE

Sandi Enders, OTR
Children's Hospital at Stanford, Palo Alto, California
Ann Blote, R.N.
Abbey Medical, Redwood City, California
Catherine Reed-Heumann, OTR
Center for Independence of the Disabled, Belmont, CA

ABSTRACT

This paper will focus primarily on the funding issues concerned with third party reimbursement in the public sector. However, the information is in principle also applicable to private funding sources, especially insurance companies.

INTRODUCTION

In the US Congress Office of Technology Assessment's recent report Technology and Handicapped People (1), the major conclusion reached was that "despite the existence of numerous important problems related to developing technologies, the more serious questions are social ones--of financing, of conflicting and ill-defined goals, of hesitancy over the demands of distributive justice, and of isolated and uncoordinated programs.

DISCUSSION

Funding issues are generally the bottom line in the actual provision of technology for disabled people. We can research, develop, transfer to private sector, utilize, build and adapt; but if payment is unavailable, the device--be it simple or sophisticated--will not reach the intended user, the disabled individual.

The emerging area of service delivery in rehabilitation engineering has developed several innovative methods for getting equipment paid for. However, in these changing times of belt tightening and increasing budget cuts, we are going to have to become more sophisticated to obtain funding for even the simplest devices. We will also need to expand the concept of the rehabilitation team to include the professionals most qualified to assist with basic funding issues: the Durable Medical Equipment (DME) supplier--both the commercial vendor and specialized rehabilitation engineering service providers.

A study (3) at Children's Hospital at Stanford (CH@S) found that lack of funding accounted for 46% of the people who did not receive a device after an initial evaluation for a seating or positioning device. This figure is based on data from services between 1974-1978. Based on informal surveys in the community, the numbers of people being denied equipment seem to be increasing dramatically. The problem is most prevalent in the areas of reimbursement controlled by public legislation.

In the CH@S study, payment sources were determined to be:

PAYMENT FUNDING SOURCES

Private insurance	26%	
Self paid	8%	Private = 39%
Voluntary agencies	5%	
MediCal (Title XIX)	27%	
Regional Centers	12%	
Calif. Children's Service	6%	Public = 48%
Champus	2%	
Dept. of Rehab.	1%	
Uncollectable	13%	

The first three sources are combined to reflect private funding sources; i.e., sources not controlled by public legislation. The next five sources are combined to reflect public funding sources; i.e., sources that are controlled by public legislation. When the "uncollectable" figure, which was written off by CH@S and is privately controlled, is added to the private sector sources, the breakdown becomes:

Private Sector Funding	52%
Public Sector Funding	48%

For both rehabilitation engineering service centers and commercial vendors of durable medical equipment, the most difficult funding procurement problems are in the realm of public sector reimbursement. The process of securing funding for the group of people who are, by eligibility for participation in these public programs, the neediest, can take up more than 90% of the time spent on funding paperwork. It is not uncommon for DME suppliers to have one or more staff persons whose sole responsibilities are for MediCare and Medicaid (Title XIX) billing.

If devices are to reach the persons who need them, the issues surrounding funding must begin to surface, so they can be more clearly dealt with. In this area of health and social welfare, many, if not most people, are very uncomfortable putting the obvious needs of disabled individuals onto the same ledger line with money. But until the world is a more ideal place, we unfortunately must live with these new equations.

To start with, a clear understanding of the funding process for obtaining a piece of equipment is needed.

OBTAINIING A DEVICE: THE FUNDING PROCESS

Step 1. Recognize problem.

process - person recognizes a problem for which a device could provide the appropriate solution.

person - physician; therapist; client; family; vendor; insurance company; public health nurse, etc.

Step 2. Document need (Diagnosis).

process - Identification of need in terms of the functional limitation of the client. Describe condition of patient briefly as a diagnosis, and state duration of need.

person - Must be a professional, for credibility: the physician and/or therapist.

Step 3. Identify equipment (Prescription)

process - Determine which device/s and accessories are required for optimal performance.

person - Physician, therapist, DME supplier (vendor, and/or rehabilitation engineering service), client, family, information service, etc. Ideally, all involved persons should work together as a team.

Step 4. Determine funding source/s.

process - Decide who is most likely to pay for the equipment, based on client's private resources and/or eligibility for publicly funded program.

person - Often the DME supplier performs this task. Ideally, the client or family would take this responsibility, relaying the information directly to the vendor, or indirectly through the therapist or other health care worker to the vendor.

Step 5. Determine Alternate Equipment.

process - Based on funding patterns, reimbursement experience, and authorization request denials, prescribed device may not be currently reimbursed by the funding sources available to client. Describe other devices which can be funded that could adequately meet client needs. Include the long and short-term compromises of using the alternate equipment.

person - DME supplier.

*ADD STEP Evaluate Step 5.

process - Determine if compromises about fundable devices are acceptable. If not, GO BACK to Step 4 and look for additional sources of funding or determine an alternative to purchase: e.g. can it be made "do-it-yourself", borrowed from an "equipment loan closet", etc. Or, GO BACK to Step 1 and see if there is an acceptable way to solve the problem without the use of equipment.

person - Rehabilitation team.

Step 6. Collect and Submit Paperwork.

process - All necessary documentation should be submitted in the first request for funding to expedite delivery of equipment and reimbursement. It is important to know what to collect. Guidelines for inclusion of relevant data should be used to reduce reporting time; develop and use a standard form and/or a checklist of items to include. In all descriptions, describe the equipment in relationship to the client, stressing the benefits, the equipment and each feature will provide the client; do not belabor the equipment itself.

person - DME supplier gathers and submits; other members of the rehabilitation team provide sufficient written material.

Step 7. Authorization received.

process - permission to provide the equipment is obtained at an acceptable reimbursement rate. Equipment is provided.

person - DME supplier

OR

Step 8. Authorization denied.

process- If a request is turned down, determine if it is because of lack of program funds, or because the case has not been clearly presented. Is the denial based on a general policy decision (which would then need to be changed at the policy making level), or on a discretionary decision by an individual reviewer.

person - DME supplier, or other team member, as appropriate.

If there are program funds, and an adverse policy decision does not exist, go on:

Step 9. Justify need more throroughly.

process - Return to Step 6 and collect more complete data.

person - DME supplier and other rehabilitation team members.

Repeat Step 7.

Success! Next time, try to include all necessary information in initial documentation, so this time-consuming second iteration can be avoided.

OR

Repeat Step 8.
Repeat Step 5.
Repeat Step 9.

...Beware! This can be an extremely frustrating process, and a seemingly endless loop. It may seem that your only option is to give up and live without the needed equipment.

To facilitate the funding process, the following resources should be developed:

o Guidelines are available, or can be developed, in cooperation with a good local DME supplier and/or third party payment sources. These should include formats for a good prescription, letter of justification of need, and any other necessary supporting documentation.

o Information on the relationship between functional limitations and equipment needs is available, and can be used for report writing as well as for direct inclusion in the documentation package.

o Literature is available which focuses on the specifics of funding for devices. Four publications are listed in the bibliography. Three of these are geared to communication aids because these devices have been so difficult to fund. However, the information is also applicable for other "easier to fund" types of devices.

It is interesting to note that a considerable part of the literature refers to the appeals process. For much equipment, this could be avoided if an additional step were added to the funding process (see *ADD Step, Evaluate Step 5) and if in Step 6, the therapist and other professionals could provide the most complete information available. By complete is meant complete in the eyes of the funding agency beholder, which may be very different than a complete therapy or treatment report, and probably a lot shorter and more succinct. When writing, put yourself in the chair of the funding reviewer: what data would you want if you'd never seen the client, and were trying to stretch limited funds to meet enormous needs. Once the process of seeking funding has been initiated, persevere and appeal denials. The appeal process is educational for the third party payer and successful appeals are precedent setting for future requests. They force review of general policy by the third party organization. However, care must be taken in selection of the first case to be presented and in specifying criteria for effective use of system and other services that will be required as part of the process (2).

Time to do fundraising takes away time from actual provision of services. More time is needed to educate fundraisers, funding agencies, do paperwork and sort out problems in getting funding.

This raises the question of who should bear the primary responsibility for securing payment for equipment and related services: the user or the service provider. Additionally, questions of conflict of interest may be raised when the equipment supplier is also the primary advocate for funding. How can equipment suppliers get out of this "middleman" position? One approach is to treat fundraising as a team effort. This becomes especially important when considering alternative funding sources. The team includes the client and the family. As we become more informed on funding issues, we can train and counsel our clients and their families to become more active participants. We can also broaden the team to include the commercial vendor throughout the entire process. These people are experienced in the funding process, and work with it daily. As we move farther away from the traditional funding process as outlined above, it is vital that the client and family become the prime advocate. When resorting to legal recourse, for appeals, it is important that this procedure be conducted by the potential user of the equipment, the family or advocate rather than the providers of service or arbitrator.

FUNDING BIBLIOGRAPHY

Funding Book: The Many Faces of Funding..., Anna Hoffman. Phonic Ear Inc., 250 Camino Alto, Mill Valley, CA, 94941. $25.

Funding of Mobility Equipment: Current Issues and Strategies. Virginia Ruggles, Muscular Dystrophy Association, 810-7th Street, New York, NY, 10019, 9/81.

Funding of Non-Vocal Communication Aids: Current Issues and Strategies. Virginia Ruggles, Muscular Dystrophy Association, 810-7th Street, New York, NY 10019, 30 pp.

Guidelines for Seeking Funding for Communication Aids. Donna DePape and LaVonne Krause. Revised 1980. Trace Center, Waisman Center, University of Wisconsin, Madison, WI, 53706. 44 pp.

ACKNOWLEDGEMENT

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REFERENCES

1) Office of Technology Assessment, U.S. Congress, Technology and Handicapped People, Washington, D.C., U.S. Government Printing Office, May 1982.
2) "Report on the Advanced Topical Discussion: Funding Strategies for the '80's". Fifth Annual Conference on Rehabilitation Engineering, Houston, TX, August 1982. Rehabilitation Engineering Society of North America, 4405 East-West Highway, Bethesda, MD 20814.
3) Team Assessment of Device Effectiveness, Rehabilitation Engineering Center, Children's Hospital at Stanford, Palo Alto, California, October, 1980.

*Sandi Enders, OTR
Technology Resource Center Project Coordinator
Rehabilitation Engineering Center
Children's Hospital at Stanford
520 Willow Road
Palo Alto, CA 94304

15.3

THE REHABILITATION TECHNOLOGIST AND THE REHABILITATION ENGINEER AS VEHICLES FOR THE DELIVERY OF APPROPRIATE TECHNOLOGY

Nigel Shapcott, R.E. and Elaine Trefler, OTR. M.Ed.

University of Tennessee Center for the Health Sciences
Rehabilitation Engineering Program
Memphis, Tennessee

BACKGROUND

In November, 1976 the University of Tennessee hosted a meeting in Knoxville to formulate recommendations and guidelines for the systematic development of education, technical training, and certification programs in Rehabilitation Engineering. It was estimated at that time that there was an immediate need for 250 qualified Rehabilitation Engineers and a future estimated need of approximately 2,000. Major recommendations which evolved from this meeting included:

1. the development of a three year federally sponsored pilot education program which would eventually result in a Master's degree in Rehabilitation Engineering,
2. that a series of continuing education programs for Rehabilitation Engineers in other disciplines be evolved,
3. that a certifiction program for Rehabilitation Engineers be developed, and
4. that there be a national coordinating body to establish and advise agencies of government in respect to programs in Rehabilitation Engineering.

PROBLEM DEFINITION

It has been estimated that approximately 3% of the United States population has a physical disability and could benefit from Rehabilitation Engineering Services if they were available (1). There are probably 30-50 Rehabilitation Engineers actively involved in service delivery (2).

For the United States this gives a potential caseload of 120,000 to 200,000 clients per Rehabilitation Engineer.

This is obviously a situation which should be changed, but we have yet to see, in the fifteen or so year history of Rehabilitation Engineering, much improvement.

To date only one Masters Degree program has been developed. This program at the University of Virginia in Charlottesville (in operation since 1979) graduates approximately five to six engineers per year. This slow rate of increase in the number of Rehabilitation Engineers suggest that an alternate system be evolved to meet the needs of the people requiring technology related to their disability. Five to six new people per year is totally insufficient in meeting these needs.

The main reasons for these low numbers are:

- There is a lack of awareness, both in public and professional health care providers of all levels, of the existence and function of Rehabilitation Engineering.
- Traditionaly there has been an economic disincentive for engineers to enter the field of Rehabilitation Engineering. The pay scales of Rehabilitation Engineers remain low in comparison with engineers in industry.
- There is a total lack of career structure.
- There is, in most cases, a lack of operational structure.

APPROACHES TO THE PROBLEM

The issues to be addressed in this paper are:

- the low number of technology providers for disabled people,
- the lack of career structure,
- the lack of operational structure.

Since there are so few Rehabilitation Engineers, they need to increase efficiency in order to apply appropriate technology at a reasonable rate. This can be achieved by applying themselves to not just tool making, but to system designing. The Rehabilitation Engineer (through RESNA) needs to define and implement the system as well as the tools by which technology is delivered. The system should be designed to train people who are not engineers to be technology providers.

Tools

The development of tools to "treat" clients can mean that the "treatment" or "device" can be applied by properly trained persons other than engineers; such as, Physical Therapists, Occupational Therapists, and Speech Pathologists because specialized engineering expertise is not required. Examples of these are: vacuum consolidation for positioning; the MPI simulator for specialized seating; commercially available communication devices and suitable interfaces; and pressure measurement pads for quantifing seating pressure problems.

Development of such tools is, therefore, an opportunity for the Rehabilitation Engineering profession to, in effect, multiply it's numbers. This leads us to a system which might be used to approach the problem.

System for Producing Rehabilitation Technologists

By judicious education (practical/hands on), the provision of appropriate tools, an understanding of information retrieval methods for technological devices, and adequate homebase resources, therapists (there were over 55,000 registered Physical Therapists and Occupational Therapists in the United States in 1982) may become more effective providers of appropriate technology for the physically disabled; that is, "Rehabilitation Technologists".

The advantages of aiming an educational course at this group are:

- if only a small fraction of 1% of over 50,000 therapists become qualified in Rehabilitation Technology, it would significantly improve the existing low levels of delivery and visibility of technology to disabled people.
- There are existing career and pay structures for this group.
- There are existing operational structures for this group.

This should not be looked at as an attempt to replace Rehabilitation Engineers with Rehabilitation Technologists, rather an attempt to provide appropriate technology to severely physically handicapped people at a reasonable rate.

An educational course has yet to be designed for the hypothetical Rehabilitation Technologist, but its aim should be to graduate individuals who are able:

- to deal with technology,
- to alter existing technology and recognize when they cannot,
- to position objects and people functionally,
- to obtain detailed information on technological devices,
- to make use of existing information systems.

Occupational Therapists, in particular, have been involved intimately with the provision of technical aids in the field of rehabilitation. Knowledge of commercially available ADL aids, mobility aids, etc. have all been part of the training of the therapist since the beginning of formalized programs. However, the approach of the therapist is often a one-on-one solution based decision making. The products are usually commercially available or slightly modified. Those which are designed by the therapist tend to be functional but often unaesthetic and made from low technology materials and techniques.

Educational Program for Rehabilitation Technologist

The proposed program would take the therapist, who has considerable background in disability, medical terminology, etc., and expand his/her knowledge of materials, methods, designs and biomaterials so that he or she can go beyond the stage of the conventionally trained therapists in the provision of technology. The components of the proposed program for Rehabilitation Technologists might include development of practical skills in:

wood;
metals;
plastics, foams;
electrical circuitry, electronics, computers;
drafting, designs, planning systems;
aesthetics, finishing, upholstery;
workshop initiation, tools, materials, stores;
clinical applications, evaluation, planning, manufacture;
communication devices;
mass production, marketing, orientation recognition;
cost effectiveness;
workshop safety;
fasteners;
simple stress analysis (statics);
compatability of materials;
biomechanics.

Educational Program for Rehabilitation Engineers

Another approach which might be considered in parallel is the supplemental education of engineers who wish to enter the field of Rehabilitation Engineering in line with the job description or the role delineation as defined in the report on the Knoxville meeting in 1976. Supplemental curriculum should include the following areas.

1. A program in team management and group dynamics would help considerably in enabling the Rehabilitation Engineer to participate in the dynamics of a rehabilitation team. To be able to speak the "same language" on an equal level would greatly enhance the ability of the Rehabilitation Engineer to be a dynamic member of an already existing team.
2. A course in medical terminology would enhance the ability of the Rehabilitation Engineer to communicate with medical professionals.
3. A course in disability is essential. It should not only include the medical aspects of disability but the therapeutic, functional, and psychological aspects as well. For example, in dealing with an individual with multiple sclerosis, it is

essential that the engineer understand the euphoria and the depression which go side by side. This will help him/her understand that a piece of a piece of equipment can be accepted or rejected based on the psychological status of the individual concerned, not on the design or usefulness of the piece of equipment. Another example would be with the individual with Duchenne Muscular Dystrophy. These young people tend to be very intolerant to a change in body position because the effects of gravity on their funcational skills are so great. There is a tendancy to design equipment which will enhance their function but they will not accept it if it at all jeopardizes their body position in space. Understanding these psychological and physiological factors will greatly enhance the ability of the engineer to design appropriate equipment.

4. Practical skill development should include: seating, pressure sore management, mobility; establishing clinics; man/material interface; clinical administration, record keeping; third party payers, grant writing; clinical applications, evaluation, planning, manufacture, aesthetics, finishing skills, upholstery.

5. Finally, the engineer needs an orientation into the environment in which the disabled person must live. Equipment which is not aesthetically acceptable to the client will not be used. Equipment which cannot be easily taken in and out of the home or the work place will again not be used even if it does provide the function for which it was designed. These environmental factors are essential in terms of the holistic approach.

CLOSING COMMENTS

Therapists need not be threatened by the proposal that a futher program is necessary in order to provide up-to-date current technology. The area of technology is expanding so rapidly that the undergraduate programs cannot in any way meet the challenge of providing current technology for handicapped individuals. Occupational Therapists and Physical Therapists working with Rehabilitation Engineers form the ideal team.

However, in areas where Rehabilitation Engineers are either few in number or do not exist at present, an Occupational Therapist or Physical Therapist having undertaken the program previously discussed could really expand the repertoire of technology which is provided to handicapped individuals under his or her care. Likewise, neither should the Rehabilitation Engineer be threatened by Rehabilitation Technologists. Our mission is to ensure the delivery of appropriate technology to people who have physical handicaps. The Rehabilitation Technologist will enhance our ability to do that and will refer to Rehabilitation Engineers when they recognize that a particular case requires more specialized involvement.

The Rehabilitation Technologist concept has potentially less barriers to providing appropriate technology to persons with handicaps than Rehabilitation Engineers working in insolation.

i. There are at least 55,000 people (the therapists) already involved in the application of technology the problems of the handicapped. A small fraction of these could significantly effect this process for the better.

ii. The career structures of this group are existing.

iii. The pay structures of this group are existing.

iv. The operational structures of this group are existing.

v. The payment for services structure of this group are existing.

vi. Approximately 6 million people could benefit from these services (1).

vii. The Rehabilitation Technologist would be in an ideal position to identify problem areas to be tackled by Rehabilitation Engineers.

The Rehabilitation Technologist concept is viable and should be pursued with vigor by RESNA.

REFERENCES

1. Rehabilitation Engineering, A Plan for Continued Progress II, U.Va. 1978.

2. Personal Communications, Douglas Hobson, REC, Technical Director, Memphis, TN 38163.

Nigel Shapcott
University of Tennessee
Rehabilitation Engineering Center
682 Court Avenue
Memphis, TN 38163

AN APPROACH TO THE QUICK AND EFFICIENT USE OF PERSONAL COMPUTER TECHNOLOGY BY PEOPLE WITH DISABILITY: SERVICE DELIVERY THROUGH A SELF-HELP CONSUMER ORGANIZATION

Mary Dellutri
Committee on Personal Computers and the Handicapped
(COPH-2)

INTRODUCTION

It is widely recognized that the use of computer technology by many persons with disability will be essential if they are to work, learn, and compete at the same level as persons without disability in our society. COPH-2 (The Committee on Personal Computers and the Handicapped), a self-help consumer organization, recognizes the importance of computer technology for persons with disability. COPH-2 members, professional and non-professional, and with and without disability, work as peers to carry out their purposes of finding, evaluating, and dispersing relevant information, and assisting members in using such information.

THE NEED FOR A CONSUMER-BASED PROCESS

Early in 1981, three adults with disability who were members of Illinois COPH(Illinois Congress of Organizations of the Physically Handicapped) and a graduate student from the Northwestern University Rehabilitation Engineering Program discussed the benefits of computer technology for people with disability. The four, who were experienced in the uses of personal computers for environmental control and as vocational and educational tools, focused on three issues: the under-utilization of the outcomes of research and demonstration projects dealing with disability and personal computers, the need for a more rapid exchange of information among persons with disability, and the threatening "cultural gap" which would develop if some persons with disability remained computerless in a society in which computers were evident at every level.

The four agreed that, in their experience, R and D projects for persons with disability often had impact upon only a small population. In their opinion, first, the problem-solving experiences of professionals working in the field needed to be transferred more quickly and to a broader number than was presently the case; second, the COPH-2 founders agreed that persons with disability themselves were not sharing their experiences with hardware and software with other people with disability who could benefit; and third, the emerging information industry was producing much that was potentially useful for persons with disability and, unlike in the past, this information was not being flowed through the rehabilitation network. It was decided that the formation of a new consumer-based group, structured to assist in the more rapid use of information, was necessary to forestall the potential cultural gap.

The group would be consumer-based so that members could establish their own needs and pursue answers. Evaluation of the usefulness of the materials gathered would be an expected part of the process. The group would interact as peers. Respect for the importance of personal computers to persons with disability would be the common bond.

What kinds of people have responded to the need for a consumer-based group which COPH-2's founders saw and articulated? A programmer and musician from the Midwest, with blindness, employed as a data processing course instructor, a rehab engineer from NUREP who is a technical expert in the field, a pediatrician from the East Coast who is the father of a young son with disability, a young woman with blindness employed as an information specialist who wants to remain competitive in her field, a high-school teacher of children with and without disability who is the father of a disabled child, a woman linguist with severe speech impediment and cerebral palsy, a father who is wheel-chair bound and almost totally quadriplegic who wants to use the computer as an educational aid for his two young children, and more, considerably over 200 more persons, in fact, have joined COPH-2.

It is important to note that though COPH-2 members have a healthy respect for computer technology, there is no naivete about the limitations (some almost insurmountable) of present-day computer use by those with disability.

FORMAL STRUCTURE

As mentioned above, three of the originators of COPH-2 were members of Illinois COPH, a consumer umbrella group chartered approximately eighteen years ago in Illinois as a not-for-profit organization, and consisting of about 3,000 members. Convinced of the timeliness of the idea, Illinois COPH charged its Education Committee to form COPH-2 as a committee under it. This arrangement provided distinct advantages for COPH-2. It could use Illinois COPH's pre-existing legal and committee structure, its tax deduction capabilities, its human resources, its finances, and its philosophical stance.

The consumer-advocate legacy of Illinois COPH provides a congenial base for COPH-2's own advocacy. For example, in 1981 when the Johns Hopkins First National

Search took place, COPH-2 officers were critical of the slowness with which information on the national judging surfaced, were dismayed to find incomplete contact information in the Proceedings catalog and in other descriptions of the project, and were uncertain whether the project results would concretely benefit persons with disability in a reasonable time frame. COPH-2 made its concerns public in its newsletter, LINK AND GO, and was given a national forum in the COPH BULLETIN, a publication of COPH. Favorable responses ensued, and a newly-constructed method for disseminating project results was developed to the satisfaction of everyone.

CHARACTERISTICS OF COPH-2

As a self-help group, all of the services of COPH-2 are carried out by members who volunteer their time and resources. In the two years of its existence COPH-2 has established a variety of systems to carry out its services: bi-monthly meetings, computers on loan to members, a library service, a special member directory, hardware and software development, a newsletter, and a technical assistance group.

To serve the communication needs of the half of COPH-2 members who are from the Chicago area, the group holds six yearly meetings five hours in length. Meetings are held co-jointly, in a mainstreamed manner, with a group named CACHE (Chicago Area Computer Hobbyist Exchange), an eight-year-old computer user's group with about 600 members. This technique for avoiding social isolation also brings to COPH-2 the many resources of CACHE: equipment demonstrations, programs, SIG (Special Interest Group) meetings, software exchange, and so on.

In the first part of the meetings COPH-2 members set up their personal computers and allow informal inquiries and hands-on experience. Two-hour formal presentations on personal computers follow. These presentations have dealt with young persons and disability, aids for persons with visual impairment, hardware adaptations, and the applications of home-based personal computers.

The library with its hard-won information is available for perusal at meetings, and the three computers on loan to members are also exchanged at meetings. This unique COPH-2 service was established in order to give members an opportunity to learn how to operate a computer in the comfort of their own home for an extended period of time. COPH-2 owns three TRS-80, model I, level 2, 16K machines. Two were donated by COPH-2 members and one was purchased by Illinois COPH. The machines, loaned at no charge to members for one to two months, are maintained through an anonymous member donation earmarked for this purpose. Coordination of current and future borrowers is done from home by a COPH-2 member with a high-level spinal cord injury. COPH-2 hopes to be able to provide other popular computer systems for its members on loan soon.

In the meantime, COPH-2's directory, ENTER-ACT, which lists not only member names and addresses but also whether a member owns a system and if they are willing to loan it for brief periods, is another resource for members who want to borrow a computer. It is also a useful resource to elicit evaluative comments about a particular system from member/owners. ENTER-ACT was conceptualized by a COPH-2 officer with cerebral palsy who regularly prints out updates for members on her Apple II.

Both ENTER-ACT and LINK AND GO, COPH-2's newsletter, are available on tape for members with visual impairment. The newsletter, which comes out three to four times per year, reflects the current focus of COPH-2 members and programs. For example, the major thrust of a recent issue was the presentation of computer devices for those with blindness following a demonstration of such devices at a COPH-2 meeting. The newsletter also contains regular columns including a very direct example of service delivery in written form, "Linking Up," a column in which COPH-2's Technical Assistance Group (TAG) replies to questions about computer hardware and software for persons with disability from members across the country.

TAG was formed to enable COPH-2 to reply quickly and efficiently to the many technically-oriented inquiries regularly received. TAG also evaluates materials and devices which come to COPH-2's attention and investigates those which warrant it. It is very important for members to establish confidence in the appropriateness of a system they intend to purchase. TAG, which consists of a committee of five COPH-2 members who are experts in diverse technical areas, can help establish this confidence.

Occasionally, the need among COPH-2 members for a particular piece of software or hardware becomes apparent and COPH-2 makes every effort to use the resources of members and friends to find a solution. For example, several COPH-2 members with limited hand control required a keyguard in order to enter data properly. The available keyguards were expensive and they fastened permanently to the keyboard making it inoperable for non-disabled spouses and family members. A COPH-2 member who is a wheelchair user with paraplegia and who is also a computer video artist and an assistant professor volunteered to design and field-test prototype keyguards for the TRS-80 and the Apple II. With monies from Illinois COPH, COPH-2 manufactured the keyguards in quantity. COPH-2 members can now purchase easily-removeable keyguards for the TRS-80, models I and III, and for the Apple II plus for $25 (including packaging, insuring, and postage) while comparable keyguards begin at $110 in the marketplace. The packing, insuring, and postage process is coordinated by a husband/wife team, both members with disability.

DISCUSSION

Is COPH-2 meeting a need? The answer, COPH-2's Executive Committee agrees, is an emphatic Yes. Evidence is in the numbers of persons who have joined COPH-2 and in the high rate of member renewals. COPH-2 has not needed to seek publicity; a notice about us in a local newspaper, a brief reference to us in a national rehabilitation-oriented pamphlet, and remarks made by a COPH-2 officer in a public setting have brought COPH-2 a deluge of inquiries, long-distance phone calls, and correspondance from abroad.

COPH-2 must now consider issues such as whether to pursue a national or local thrust. Is it more important to dispense information widely or provide services to local members? In order to conserve energies, COPH-2 must avoid providing already existing service (such as computer literacy training) but be aware of, and direct members to, these resources in the community. Finally, COPH-2 must investigate the appropriateness of expansion and of seeking avenues for funding.

SUMMARY

The service delivery record of the past year indicates that COPH-2: loaned three TRS-80 personal computers for a one-to-two month period to 16 individuals; distributed over 70 articles from its library to more than 30 members; conducted seven structured workshops at meetings; designed, tested, and fabricated 20 keyguards for the TRS-80, models I and III, and the Apple II plus and made them available for the low cost of $25; organized a five-member Technical Assistance Group which is available via verbal and written communication for free consultation; published four documents (averaging 12 pages) containing specialty articles, meeting summaries, library material descriptions, letter exchanges, and announcements; and produced a unique membership list containing data which encourages members to relate and interact on common bases.

COPH-2 embodies a new social form in which professional and non-professional people with disability, rehabilitation providers, and information industry representatives all interact as peers. The purpose as a self-help group is to enhance, rather than duplicate or compete with, the information, products, and efforts of others. It is believed that a quick and more efficient delivery of services to members can help end the discrepancy between computer use in society at large and use of that technology by persons with disability.

ADDRESS: COPH-2
2030 West Irving Park
Chicago, Illinois 60618

ASSISTIVE DEVICE INFORMATION RESOURCES

Bernett, J.
Southwest Research Institute

ABSTRACT

Effective solution of assistive device problems demands utilization of existing information resources. An overview of the spectrum of resources which have been used successfully through the 6-year course of a rehabilitation engineering service delivery program is presented.

INTRODUCTION

When a disabled individual encounters a problem concerning adaptive equipment, what resources can be tapped to help achieve a successful solution? The most immediate resource is our personal experience and common sense. By listening, discussing, questioning, translating, interpreting, and clarifying, much can be done to acquire a reasonable problem definition. Such a process also taps the most essential resource, the disabled individual. Having defined the problem with the help of the user, it is then appropriate to explore a multitude of available resources.

The information resources of potential benefit to a service delivery program appear to be somewhat scattered. There is no systematic method for identifying the resource. Only by sifting and sorting through the variety can one recognize the many alternatives available. The following discussion includes only some of these alternatives. The categories suggest types of resources that have proven helpful to the author.

LOCAL RESOURCES

With few exceptions, local resources are most useful because of availability and accessibility. Specific resources vary in different geographies, but usually include fellow staff members, rehabilitation facility programs and staffs, state agencies, medical practitioners, university engineering programs, medical and technical libraries, rehabilitation equipment vendors, handicapped consumer groups, independent living centers, etc. Becoming familiar with and using these resources, a network of useful information exchange is created.

In addition to these commonly accepted rehabilitation related resources, there are resources that were not necessarily intended to respond to adaptive equipment needs, but can make a unique contribution.

EQUIPMENT VENDORS

Equipment vendors are extremely valuable information resources. They can almost instantly provide literature on commercially available equipment and alert us to new equipment developments. The local vendor can provide details on particular equipment that can be readily purchased, equipment service and repair options and identify individuals in the area that have had user experience with a particular product. In some instances, the vendor can provide an equipment demonstration or arrange a trial use period for the client.

Though some equipment vendors routinely provide equipment customization services, most distributors do not offer special adaptations to the products they sell. However, some may provide simple modifications if the need is clear.

In most instances, once contact has been established with equipment manufacturers and distributors, you will be placed on a mailing list or phone list and will continue to receive product literature and up-date information.

JOURNALS AND NEWSLETTERS

As an equipment information resource, journals offer a regular and timely means for pointing out equipment availability, related programs and services and customer equipment problems and needs. Scanning relevant journals and newsletters is essential to an awareness of the types of information being presented to handicapped individuals and members of the rehabilitation community and they can help us to better understand how product information expertise and services can appropriately fit into the overall rehabilitation picture.

The following list includes a sampling of journals and newsletters that provide information in several subject areas and equipment categories. Newsletters/periodicals describing relevant programs and activities at the local and state levels should be added to this list. Rehabilitation facilities, independent living programs, educational facilities and state agencies are potential sources of these local publications.

Accent on Living - Quarterly
Cheever Publishing, Inc.
Gillum and High Drive
P.O. Box 700
Bloomington, IL 61701

Bulletin of Prosthetics Research - Biannually
Department of Medicine and Surgery
Veterans Administration
Washington, D.C. 20420

Homecare/Rehab Product News - Bimonthly
Miramar Publishing Co.
2048 Cotner Ave.
Los Angeles, CA 90025

Paraplegia News - Monthly
5201 N. 19th Ave., Suite 111
Phoenix, AZ 85015

Rehab Brief - Monthly
Institute for Information Studies
200 Little Falls St., Suite 104
Falls Church, VA 22046

Rehabilitation Digest - Quarterly
Canadian Rehabilitation Council for Disabled
One Younge St., Suite 2110
Toronto, Ontario MSE 1E5 Canada

Rx Home Care - Monthly
Barrington Publications, Inc.
825 S. Barrington Ave.
Los Angeles, CA 90049

Technical Aid to the Disabled Journal - Quarterly
c/o Royal Ryde Rehabilitation Hospital
227 Morrison Road, P.O. Box 108
Ryde, N.S.W. 2112 Australia

The Pathfinder - Bimonthly
National Rehabilitation Information Center
4407 8th St., N.E.
The Catholic University of America
Washington, D.C. 20017

EQUIPMENT DIRECTORIES

Various equipment and service directories serve as good starting points for determining product availability. Subsequently, specific details can be easily obtained by writing or calling the indicated source. In addition to the following list of basic rehabilitation equipment resources, various industrial equipment and supply directories, office equipment directories, local commercial product listings, the Yellow Pages and even the Sears, Roebuck Catalog can provide valuable equipment identification and availability information.

Accent on Living Buyer's Guide
Cheever Publishing, Inc.
P.O. Box 700
Bloomington, IL 61701

Green Pages Rehab Sourcebook
P.O. Box 1586
Winter Park, FL 32790

Home Health Care/Rehab Products' Directory and Resource Guide
Miramar Publishing Co.
2048 Cotner Ave.
Los Angeles, CA 90025

Rx Home Care Directory of Manufacturers, Products and Services
Barrington Publications, Inc.
825 S. Barrington Ave.
Los Angeles, CA 90049

Technology for Independent Living Resource Guide
Prepared for Instructional Course - Aug. 1982
RESNA
4405 East-West Hwy., Suite 210
Bethesda, MD 20814

REPORTS

Current annual activity reports from the Rehabilitation Engineering Centers are beneficial equipment references. Many centers publish additional materials focusing on particular adaptive device development or modification, device test results and applications. Since individuals associated with REC programs are specialists in unique core study areas, they can sometimes suggest resources related to these study areas in your own geographic location.

CONFERENCES AND EXHIBITS

In addition to the RESNA Conference, there are other conferences that may address adaptive equipment availability, equipment applications and patient/client assistive equipment needs. Some offer extensive equipment exhibits, where demonstrations can be observed and personal interactions with a large group of equipment representatives can occur. Product literature is good reference material, but there is no substitute for hands-on demonstration. Organizations sponsoring relevant conferences are listed below. State and local chapters of these organizations also sponsor beneficial conferences and workshops. Industrial equipment shows, educational and vocationally related equipment exhibits sometimes held at the local level provide useful resource information.

International Abilities Unlimited Expo
2945 Harding St., Suite 107
Carlsbad, CA 92008

American Occupational Therapy Association
6000 Executive Boulevard
Rockville, MD 20852

American Physical Therapy Association
1156 15th St., N.W.
Washington, D.C. 20005

American Speech-Language-Hearing Association
10801 Rockville Pike
Rockville, MD 20852

National Association of Medical Equipment Suppliers
618 South Alfred
Alexandria, VA 22314

National Rehabilitation Association
1522 K St., N.W., Suite 1120
Washington, D.C. 20005

ACCENT ON INFORMATION

Accent on Information (AOI) is a commercial computerized product database with data entries organized by categories of equipment function. The information requestor indicates on a check-off form (found at the back of every Accent on Living magazine) the category of aids for which information is desired. In addition to commercial product data entries, the system includes some interesting "how-to" solutions to problems that have been contributed by readers. In response to an information request, a computer print-out is received by mail. Each data entry lists the device name, company address, cost and a brief description. Search cost is $12.00.

ABLEDATA

Designed to organize rehabilitation product information at a national level, the ABLEDATA System is a computerized databank offered as a service of NARIC at The Catholic University of America. Resources listed in ABLEDATA files are equipment manufacturers, national distributors and sole suppliers. Each data entry provides a complete description of the equipment item including generic name, brand name and model, manufacturer, distributors, cost and physical description. An identifier term(s) is assigned to each entry from the controlled vocabulary which comprises the system's thesaurus. An additional data field is available for equipment user comments and feedback. The informal use and evaluation information offered by the practitioner or the disabled individual for inclusion in this field is an especially valuable resource. Appropriate and special equipment applications, custom adaptations, design adaptations, installation instructions, equipment limitations, etc., may be presented in this field.

Access to the ABLEDATA System is accomplished through the trained ABLEDATA broker. The creation of a network of information brokers is a truly unique characteristic of this system. Though brokers may be located in different settings and involved in programs with differing purposes, they are using the same information bank to help them establish unique experience bases. These experiences can be shared informally with one another or sometimes incorporated into the user comment field of the system. ABLEDATA is a cooperative system in that brokers not only benefit from one another's experiences, but also share in the responsibility for recommending data items for input, up-dating data entries, and providing system use statistics. The ABLEDATA database is an excellent resource tool for identifying commercial products at a national level and may also serve as an excellent indexing system for local product catalog/literature files.

NORDIC INFORMATION SYSTEM

Though not available to this country, the Nordic Information System is an example of other countries' responses to an equipment resource need. In the not-so-distant future, effective methods and channels for international sharing of information and resources will hopefully be established. Technology utilization on a much grander scale can then be accomplished.

The Nordic Information System on Technical Aids for Disabled Persons is a computerized database containing national registers of equipment information from Sweden, Norway, Denmark, Finland and Iceland. The primary purpose of the system is "to store, arrange and in appropriate manners present information on those technical aids available in the Nordic countries."

Data elements included for each equipment item appear to be quite extensive. In addition to the basic product description, availability details, cost, etc., fields for technical data, rules of operation, installation instructions, available accessories, appropriate applications, test results, guarantee and literature references are available for data inclusion in the system.

The system's classification scheme is based on division by equipment function which is very similar to ABLEDATA's identifier term and thesaurus scheme. Because each national register of aids is presented in this country's national language, a numerical assignment for each classification term assures translation. Data entry information is primarily provided by equipment suppliers in each country, subsequently screened by each national committee which supplements information with test results, government procurement regulations, etc., before it is inputed into the database through the central coordinating office in Stockholm.

One of the primary purposes of the system is to generate printed materials, data lists and catalogs of certain categories of devices on a regular basis. Drawn pictures may also be stored in the computer system for direct photosetting. There appears to be a strong emphasis on particular data system products rather than immediate access to the on-line system.

The period of trial and evaluation of the Nordic Information System extends through the Spring of 1983.

CONCLUSION

No matter how extensive our efforts to collect, maintain and develop information resources, we will never have all of the answers at our fingertips all of the time. There will always be resources that are unfamiliar or untried because this activity is a continuous, building process that can never be termed complete. Through the continuous refining and building process, however, we learn to identify and utilize a "good mix" of resources that can provide a firm foundation for practical approaches to adaptive equipment problem solving.

Southwest Research Institute
Department of Bioengineering
6220 Culebra Road
Post Office Drawer 28510
San Antonio, Texas 78284

THE REHABILITATION ENGINEERING SERVICE DELIVERY PROGRAM AT THE REHABILITATION INSTITUTE OF CHICAGO

Kenneth P. Kozole*† and Margaret C. Pfrommer*
*Northwestern University Rehabilitation Engineering Program
†Rehabilitation Institute of Chicago

HISTORICAL BACKGROUND

The purpose of this paper is to describe the Rehabilitation Engineering Service Delivery Program (RESDP) at the Rehabilitation Institute of Chicago (RIC). The way it functions and how it fits into a large rehabilitation facility will be explained.

A definition of "Rehabilitation Engineering Service Delivery" at RIC could be as follows: A process involving the evaluation of persons with physical disabilities and the delivery of technical products and services to increase their independence and productivity.

Development of the RESDP at RIC began in October 1980, followed by actual client services during March 1981. Prior to the RESDP, rehabilitation engineering services were delivered as part of the Northwestern University Rehabilitation Engineering Program (NUREP). However, it became evident that the volume of client needs exceeded the scope or main purpose of the NUREP team which was funded to provide research and development of technical aids. Also, due to an increasing selection of commercially available technical aids, solutions to client needs became more routine and did not always require the services of an entire research team. Therefore, a process of service delivery on a fee-for-service basis was realized by NUREP and the RIC. The program was implemented by the RIC, which was already established as a recognized provider of rehabilitation services. Rehabilitation Engineering services are separate from the NUREP, which is now only used on a consulting basis. Through weekly meetings, the RESDP continues to provide feedback to the research program as to the success and failure of technical aids and their modifications. NUREP continues to provide updated information and consultation regarding technological advances in Rehabilitation Engineering. This close working relationship between service delivery and research has been advantageous to both programs.

The RIC is a private, not-for-profit, fully accredited hospital, devoted to the rehabilitation of physically disabled children, teenagers, and adults. Persons referred to RIC include those having conditions of spinal cord injury, head trauma, stroke, cerebral palsy, or other progressive and non-progressive neurological disorders. The facility is located immediately adjacent to the Northwestern University Medical School and Northwestern Memorial Hospitals on Chicago's near northside. Facilities are provided for one hundred seventy inpatients and an average of one hundred seventy outpatients daily. The RIC is designated as the Midwest Spinal Cord Injury Care System.

STAFFING AND TEAMWORK

The RESDP is housed within the NUREP facility as a result of an agreement between RIC and the NUREP which provides the RESDP access to necessary clinic space, a fully equipped tool shop (within the orthotics/prosthetics research laboratory), and an office for one rehabilitation engineer. At present the RESDP is staffed by a half-time Clinical Rehabilitation Engineer, and a half-time Rehabilitation Engineering Technician. A full-time Clinical Rehabilitation Engineer will be added to the staff during June 1983. Because of the limited RESDP staff, all efforts are made to reduce duplication of services and to utilize available resources. For example, some electrical fabrication services and computer application consultations are purchased from the NUREP by contractual agreement. Secretarial services are contracted on a need basis from the RIC typing pool (it is becoming evident that a half-time secretary would alleviate the staff from many paper handling and inventory responsibilities). A specialized seating clinic may soon be a reality; however, at this time, RIC Occupational Therapists and Physical Therapists experienced in seating and positioning perform evaluations in conjunction with the RESDP and the Orthotics/Prosthetics Department. Local orthotic venders are frequently requested to fabricate custom seating systems.

With the opening of a new center at RIC which provides comprehensive evaluation and training in the use of alternate/augmentative communication and environmental control units (The Alan J. Brown Center), the Clinical Rehabilitation Engineer has become a team member with a Speech-Language Pathologist and Occupational Therapist. A majority of services provided to this program, include controls modification, device positioning, and home installations. Ongoing cooperation and feedback from consumers is invaluable as is the help of dependable commercial medical equipment suppliers. The success of this program is due in part to the availability of other RIC support services which has allowed the RESDP to offer quality services on a modest budget. However, as the number of persons receiving RESDP services increases, so must the staff.

METHODS OF REFERRAL

RIC In-Patient Referral

The physician's order goes to the RESDP which contacts the original referral source (O.T., P.T., Communicative Disorders Therapist, etc.). An appointment for Rehabilitation Engineering service is made through the RIC Scheduling Department. Billing for service and equipment is made through Patient Accounts.

RIC Out-Patient Referral

This is arranged the same as an in-house referral, except the physican's referral can come from outside RIC.

Direct Outside Referral

The client does not have to be evaluated for all RIC comprehensive services. Only the engineering service requested is provided. A Physician's referral is necessary, and funding must be reviewed by RIC Patient Accounts.

SERVICE CATEGORIES

RESDP services are divided into the following categories, each with its own unit of charge.

- Consultation - The Clinical Rehabilitation Engineer discusses a particular need with the client and other interested parties such as family, medical team, and vocational specialist. Then makes recommendation for a course of action. A review of pertinent information such as the medical record, special evaluations, video tapes, etc., would also be considered in preparing a written report.
- Evaluation - Unlike the consultation service, evaluation may include trial use of equipment by the client. A record of events is kept and the results compiled into a written report. The report is then sent to the Department of Medical Records.
- Re-evaluation - Successive modification and equipment use trials may not require the depth of preparation as in the case of the initial evaluation (such as contacting information sources or reviewing the medical record), therefore a lesser unit charge is processed for this category of service.
- Fabrication - The Clinical Rehabilitation Engineer and the Engineering Technician fabricate/modify the technical aid and record the time involved.
- Materials - This category considers the cost of components and materials used to fabricate a technical aid and/or modification.

EVALUATION

A. Evaluation

At the RIC-RESDP, the evaluation process is performed utilizing an interdisciplinary approach which could involve the client, family, team members from RIC, teachers, vocational specialists, and others who can offer input for the benefit of the client. If the evaluation determines that a technical aid is not necessary, a referral may be made to the appropriate therapy to upgrade skills for improving independence.

If a technical aid is necessary, a determination is made as to which aid is appropriate, through trial use if possible; local venders are an integral part of this process. If the aid is not available on the market, contact is made with a research facility to consider possible development of the aid. As part of the process at the RIC, referral is made to the NUREP for further evaluation by their engineering team. This may result in research and development of the aid.

During trial use of an available technical aid, it can be determined what modifications, if any, may have to be made. Based on the trial use, a rationale is provided to third-party payers. Upon their approval, the aid is purchased and modified if necessary. It has been the intent of the RESDP to use common hardware components and materials whenever possible to keep modifications simple and easy to maintain if repairs are necessary. Sketches and/or photographs of the modifications help the RESDP maintain a record of the modification.

B. Training and Adjustment

Additional referrals to the RESDP may be required for training and adjustments during trial use. There are situations in which the Clinical Engineer may request routine check-ups to maintain proper operation, fit, and position of the aid. Follow-up usually occurs when the person using the aid initiates contact or when contact is made in conjunction with a routine physician's check-up at RIC.

Most services provided by the RESDP are conducted in the NUREP clinic space. Experience has shown that time can often be saved during evaluation and trial use of equipment, if the necessary tools and materials are near by (especially in a multi-level facility). The NUREP clinic room is adjacent to the orthotics/prosthetics research laboratory which contains hand tools and a power tool room which is used by the Clinical Rehabilitation Engineer and the Engineering Technician for fabrication. Exceptions to this evaluation site include evaluating persons in therapy, in the Alan J. Brown Center, in the home, in the school, or on the job site. Most important to any evaluation, trial use, and consequential recommendation is the user's input. Many times a client has had ideas to solve personal needs but no means to develop the ideas. Many successful applications have been a result of listening to the person and implementing his or her design. Another valuable source of ideas has been the therapist who knows what he/she wants for a particular function but does not have the tools or materials readily on hand to fabricate the aid. Frequently the therapist will provide an aid for temporary purposes using prototype materials such as tri-wall cardboard (i.e. lapboards or seating inserts), or low temperature forming plastics (i.e. "Orthoplast" handle extension for a spoon); following trial use of the temporary aid, the Rehabilitation Engineer will fabricate a more definitive copy of the technical aid or modification: "A good idea is a good idea".

FUNDING

Reimbursement for Rehabilitation Engineering services is initiated by the Rehabilitation Engineer who records the number of fifteen minute units per category of service on a standard RIC data processing form.

Once the units of time and material costs are recorded, the forms are sorted corresponding to inpatient and outpatient and are entered into the RIC billing system on a daily basis by the Data

Processing Department. The Patient Financial Service Department is then responsible for obtaining payment.

Documentation of Rehabilitation Engineering Services is provided in written report form following each client interaction. The report is completed in triplicate form and the original copy is sent to the RIC Medical Records Department, a copy is sent to the referring physician, and a copy is stored in the RESDP file. Patient Financial Services can justify the RESDP service charges to the paying party by utilizing information from the Medical Records Department.

As a team member at RIC, the Clinical Rehabilitation Engineer attends, and reports at regularly scheduled client conferences. This exposure to other RIC Staff members, in addition to frequent department inservice presentations and general daily interaction throughout RIC, has helped others understand the function and capabilities of the RESDP. This involvement has resulted in appropriate referrals to the RESDP and acceptance into the RIC system and community as a viable, growing service delivery program.

EQUIPMENT AND SUPPORT SYSTEMS

The RESDP Clinical Engineer is often involved in evaluations regarding mobility aids, environmental control systems and communication aids; however, the attending RIC therapist is responsible for ordering major equipment such as wheelchairs or environmental control systems. Once the major equipment is delivered to RIC, the RESDP is responsible for obtaining additional components or materials if modifications are necessary. This equipment ordering system has allowed the Clinical Rehabilitation Engineer to spend less time ordering equipment and to increase clinical interaction time. It does require however, good communication between the client, Clinical Rehabilitation Engineer, Therapist, Vender, and Third Party Payer.

FUTURE PLANS/NEEDS

In the near future, the RESDP will become more intensely involved in the existing RIC programs which serve special needs of persons with physical disabilities. Three such programs deal with 1) specialized seating, 2) vocational applications and 3) children who have developmental disabilities.

Specialized Seating

Seating and proper positioning is the first step in the process of applying engineering services. These as a first consideration help maximize physical function and also help achieve optimum results in the application of other engineering products and services. Increased involvement would include a more comprehensive selection of custom seating systems fabricated at RIC.

Vocational Applications

The RESDP can provide services that could help more persons with physical disabilities realize a high degree of success in a job situation. Such services would consist of work site evaluations, modifications of machines, work tools, and work stations, and resolving problems of accessibility in the work place. This work would be conducted in conjunction with the Department of Vocational Rehabilitation at RIC.

Children Who Have Developmental Disabilities

All children share a common goal that of trying to achieve their fullest potential in life. The RESDP services will be provided to help children through the various stages of the developmental process. One way this can be achieved is by modifying toys that facilitate development of physical and cognitive skills. This approach is being taken as part of an RIC program for children with spina bifida. It is hoped that with the inclusion of the RESDP, children in other pediatric programs will be benefited.

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ADDRESS

*Northwestern University
Rehabilitation Engineering Program
345 East Superior Street, Rm. 1441
Chicago, Illinois 60611

†Rehabilitation Institute of Chicago
345 East Superior Street
Chicago, Illinois 60611

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REHABILITATION ENGINEERING CLINIC
A MODEL FOR SERVICE DELIVERY

Hugh O'Neill
Children's Hospital at Stanford

Gee Gee Williams, OTR
Ralph K. Davies Medical Center

ABSTRACT

A Rehabilitation Engineering Clinic was instituted at Ralph K. Davies Medical Center in March of 1982 as a means of integrating rehabilitation engineering services into an acute, rehabilitation setting. The purpose of this paper is to share with the reader the need, plan, enactment and results of the clinic.

INTRODUCTION

The logical role of the acute, rehabilitation hospital as a consumer of rehabilitation engineering services and as a resource for identifying needs and directions for research is often under-utilized. There are many reasons for this, ranging from the unavailability of rehabilitation engineering services in many communities to the lack of a suitable model for integrating the services into the hospital. In the case where a major rehabilitation engineering center is available in the community, the hospital will weigh several criteria in its decision to seek rehabilitation engineering services. Two factors appear to be the most common reasons for the under-utilization of services:

1. The perceived cost of rehabilitation engineering services. It is difficult to compare the cost of a device or an engineering consultation against the therapist's time when he/she provides a similar service. However, the cost of engineering services is justifiable and therefore stands out.
2. The lack of understanding of the role of rehabilitation engineering and the difficulty for hospital staff to determine when engineering services are appropriate. In a clinical setting rehabilitation engineering is most often an extension of the services provided by therapists. As a result, unless the problem is clearly unsolvable by the therapist, he/she is often unsure at what point engineering input will benefit the problem-solving process. The therapist therefore will pursue other options rather than risk the time and expense of an inappropriate referral.

The Rehabilitation Engineering Clinic has been structured to address these areas. The hospital staff is encouraged to utilize the clinic as another problem-solving resource. In this role the Clinic acts as a screening body to aid in determinimg an appropriate course of action. This may include additional therapy services, in-house fabrication of a device or referral to an outside agency.

BACKGROUND

Ralph K. Davies Medical Center is a 341 bed non-profit health care institution with a 72 bed rehabilitation unit. Drawing from all of northern California, the rehabilitation team specializes in the care of spinal cord injured, brain injured and hand injured patients. Located 40 miles North of Palo Alto, the rehabilitation unit has benefited from the services offered by the Rehabilitation Engineering Center at Children's Hospital at Stanford.

The need for rehabilitation engineering services can be viewed from numerous perspectives. Many of the patients return to rural areas where it is difficult to obtain equipment. The final stage of acute care rehabilitation includes securing necessary equipment for patients. When equipment is not commercially available, solutions to unique patient problems may be resolved by a rehabilitation engineer. Spinal cord injured patients, in particular, tend to rely on devices that accommodate for their paralysis by positioning or mobility devices that substitute for decreased functional abilities.

Secondly, rehabilitation engineering has recommended and fabricated devices that have enhanced the treatment of patients. Devices such as a head positioning device for brain injured patients who lack head control and a hemi-training device for wheelchair propulsion are a couple of examples of devices that have been developed for clinic use.

Finally, the rehabilitation team acknowledges the need to have rehabilitation engineering input in resolving specific patient problems. Two occupational therapists have been designated as resource people to investigate commercially available equipment. Abledata is used as needed. When all avenues for obtaining equipment are exhausted, a rehabilitation engineering consultation request is initiated.

The Center's relationship with rehabilitation engineering was introduced via a student internship program. Although occupational therapists were aware of the profession of rehabilitation engineering (Stanford's annual conference, articles in journals, etc.), they did not utilize their services. During the Summer of 1980 a rehabilitation engineering student from the Stanford program interned for one month in the occupational therapy department. This brief introduction resulted in heightened awareness of how rehabilitation engineering could resolve many of the daily functional needs of rehabilitation patients.

The hospital has encouraged the utilization of rehabilitation engineering services whenever needs have been identified. In one case a device was needed that would allow a C-1 quadriplegic to continue his career as a painter. A private rehabilitation engineer in the community then developed an electronic easel.

With rehabilitation engineering firmly established at the rehabilitation center, a suggestion was made by the occupational therapy department to hold a once a month Rehabilitation Engineering Clinic. The suggestion was approved by administration and the medical director and the first Clinic was held in March of 1982.

METHOD

The Clinic is held on the last Friday of every month from 8:30 a.m. to 10:00 a.m. Each presentation is scheduled for 20 minutes. Because all problems need not be addressed by rehabilitation engineering, the Clinic includes the hospital's bio-medical engineer and an occupational therapist. Coordinated by the director of occupational therapy, the proposed project is reviewed for presentation a week before the Clinic. A search is done to rule out commercial availability of the device. The therapist who identified the need for the equipment or device, the rehabilitation engineer from Stanford, the hospital's bio-medical engineer, the medical director of rehabilitation and any other representative from a rehabilitation department are invited to the Clinic.

Following a 15 minute discussion of the problem, a recommendation by any of the team members is made. If the recommendation includes the device being made for a patient by the Stanford Rehabilitation Engineering Center, then Stanford's business office seeks the payment authorization for the project. If the project relates to a device that Stanford would make to meet a hospital's need, then Stanford presents a bid for the project to the hospital. If a patient related item can be made internally by the staff of Ralph K. Davies, then the Center bills the patient directly. If the project relates to a device to be used in treatment, and made by the hospital, a department head approval is sought. All four mechanisms for developing services have been utilized.

RESULTS

The Rehabilitation Engineering Clinic has met 9 times since its inception 11 months ago. During this time 17 problems have been presented to the Clinic for review (Table I). These resulted in 5 referrals to the Rehabilitation Engineering Center for provision of services on a fee for service basis. One of these was for a device to be used in the Clinic and which had two distinct parts to it. In this case the Clinic team determined that design and fabrication of one of the parts was within the capability of the hospital's staff and therefore only the other part of the device needed to be referred outside.

SUMMARY OF CLINIC ACTIVITIES

Presentations	Quantity
Problems	
Head Stabilization	3
Arm Positioning/Stabilization	3
Body Positioning/Support	2
Amputee/One-Handed Devices	2
Wheelchair or Device Control	5
Therapy Aid	1
Staff Training Aid	1
Information Dissemination	
Presentations on new devices/techniques	5

In the remaining cases, where a device eventually resulted, the team developed solutions or approaches to the problems which were then implemented by the appropriate therapist or medical instrumentation personnel. In two cases of specific patient needs, an analysis by the Clinic team revealed several alternative solutions, including devices and/or adaptive techniques. Information on the alternatives and their trade-offs was provided to the patients and in both cases the patients pursued the adaptive techniques.

In most cases the problems presented to the Clinic can be divided into two categories:

1. Devices or solutions which are primarily applicable to the Clinic, and
2. Devices or solutions which address the specific needs of a particular individual

An example of a device for clinical use is a wheelchair propulsion training device for hemiplegics. This device was developed to provide auditory feedback to the patient to reinforce the proper foot motion necessary for straight ahead propulsion using the non-involved leg.

An example of a solution for a particular patient is the individual with a spinal cord injury and bilateral hip disarticulations who was presented to the Clinic for evaluation of alternatives to enable trauma-free sitting and enhanced trunk stability. Nine of the problems proposed to the Rehabilitation Engineering Clinic have been primarily for clinical use and 8 have been for specific patients.

In 2 additional cases, RKDMC had been chosen as a clinical evaluation site for devices which were developed at other centers. One of these devices was an eyebrow activated microswitch. A therapist presented a C-4 quadriplegic as a candidate for its use. The engineers at the Clinic provided technical expertise which enabled it to be interfaced with the patient's tape recorder. In this case the Clinic provided an interdisciplinary approach to the successful use of this device.

DISCUSSION

The Rehabilitation Engineering Clinic has been functioning successfully and does appear to be resolving the problems of integrating rehabilitation engineering services into the acute, rehabilitation setting. In the first case, where cost of services has been perceived as a problem, its primary benefit has been in providing a screening mechanism for possible solutions to problems which are encountered in the hospital. Because the rehabilitation engineering team is composed of additional disciplines not typically a part of the patient's treatment team, the Clinic is able to address, as needed, those problems which might otherwise go unsolved, or solved at greater expense to the patient through successive outside referrals. The Clinic has enabled the appropriate disciplines to assemble at one time and to discuss and develop approaches to problems in a short period of time at minimal cost to the patient. In addition, approximately half of the problems presented to date have been for therapy-related needs, as opposed to individual patients, and the Clinic has enabled a team approach to be applied to problems which might otherwise have never been addressed effectively.

In the second case, where the clinical role of the engineer has been unclear to the therapists, the Clinic appears to be helpful in resolving some of the ambiguity. The Clinic is providing a vehicle to dispel the image that many health professionals have of the engineer as a builder of devices rather than as a participant in the problem-solving process.

The lack of experience of most health care professionals with engineers and the difficulty in processing a consultation request with an engineer through the hospital bureaucracy results in a number of problems never being effectively addressed. This has been demonstrated by the fact that when an engineer is on site, as during the student intern rotation, the therapists do begin to seek advice and utilize the engineer's services. However, a short time after the engineer is no longer regularly on site, the utilization of his services all but stops. The Clinic has encouraged the therapists to present problems, rather than just possible solutions, to the Clinic. This has been effective; however, it is unknown whether or not utilization of engineering services in this way would continue should the Clinic stop.

The Clinic has also functioned as a vehicle for education and information exchange. Five presentations have been given at the clinic to familiarize the hospital staff with new devices or techniques which are commercially available or under development at other rehabilitation engineering centers. Follow-up information on previous Clinic problems is also presented in order to provide closure on the problem-solving process.

A significant advantage of the Clinic is the continuity provided by having the same core team members (i.e., occupational therapist, rehabilitation engineer and bio-medical engineer) address each problem. This enables the team to base solutions to current problems on the results of similar problems encountered at previous clinics. An example is the development of a new head stabilization device.* Over a period of 4 Clinics, 3 separate therapists presented 3 brain injured patients with head control problems. Several solutions were tried but proved unsatisfactory. Each, however, was a refinement of the previous attempt and utlimately did enable the development of a device which meets the needs of many brain injured patients. The prototype device is currently being evaluated at RKDMC.

CONCLUSION

The Clinic has been effective in integrating rehabilitation engineering services into an acute, rehabilitation setting. The Clinic has been cost effective in addressing the needs of specific patients. In addition, the problems which have been addressed relative to therapy needs appear to be enhancing the general level of patient care and the efficiency of the therapists.

The Clinic has resulted in at least 4 referrals to the Rehabilitation Engineering Center which would not have otherwise been made. Furthermore, the Clinic has provided the impetus, and valuable direction, for the development of a long-needed head stabilization device for brain injured individuals.

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Hugh O'Neill
Rehabilitation Engineering Center
Children's Hospital at Stanford
520 Willow Road
Palo Alto, CA 94304

Gee Gee Williams, OTR
Director of Occupational Therapy
Ralph K. Davies Medical Center
Castro & Duboce Streets
San Francisco, CA 94114

THE LEGAL RESPONSIBILITY OF ENGINEERS: WHERE DOES THE REHABILITATION ENGINEER FIT IN?

Edward F. Ellingson

CURATIVE REHABILITATION CENTER

ABSTRACT

The design approach used by Rehabilitation (Rehab.) Engineers is contrasted with that used in other Engineering disciplines. It is noted that Rehab. Engineering matches the conventional design process from design studies through development of a single experimental or prototype unit, but does not include failure and reliability analysis, field tests, and production considerations. Potential problems are discussed because of the abbreviated approach used in Rehab. Engineering and recommendations made.

INTRODUCTION

The very nature of Rehab. Engineering makes it different from the other Engineering disciplines. This difference, in turn, is such that there may be misunderstandings about Rehab. Engineering which could result in potential for future problems.

The following sections present the design procedures used by other Engineering disciplines contrasted with Rehab. Engineering, discuss the potential problems that exist, and make recommendations for Rehab. Engineers and other professionals in the health care industry.

PRODUCT DESIGN PROCESS

The usual process of designing an engineered product follows a complex and iterative sequence of steps which can be roughly defined (1-5). The process is iterative in that each step can be repeated as necessary until successful results are achieved. There are five steps:

1. Identification of need
2. Exploration
3. Concept Formulation
4. Product Development
5. Production Engineering

These steps are defined in the following sections.

Identification of Need

The design process starts with the recognition of a need that could likely be filled by a product. The need must be described in engineering terms. Exactly what is the problem? Why won't present products fulfill the need? What are the constraints?

Exploration

The exploration phase of the design process is normally crucial and often involves a major effort. Exploration starts with the gathering of relevant information about similar projects. Patent and literature searches are typically the first step in these studies. Exploration will often involve a more detailed analysis of the user needs through market research, analysis of human factors, environmental study, or other factors.
The construction of models may also be a part of the exploratory phase. Mathematical models could be used to aid in describing the physical characteristics of a design. Hardware models could be constructed to test and demonstrate certain concepts under consideration.

The results of this exploration phase will be a better definition of a perceived solution to the given problem.

Concept Formation

All that has been learned from the exploratory and the problem definition stages must be combined into a concept design. This is normally a sketch or layout of the proposed product with a description of the important elements of the design. This concept description is used for communication to other members of the design team.

Product Development

The objective of product development is to convert the general concepts of design specifications and other recommendations into a specific product ready for final production. This is usually a 2-step process. The first is the design, fabrication and testing of an experimental unit. The second is the refinement of design parameters into ones suited for production.

The experimental design should incorporate all of the items learned preceeding this point and completely specify the form of the new product with drawings. One prototype unit is then fabricated and tested as follows:

1. Mechanical strengths tests and failure analysis.

2. Accelerated life tests and reliability analysis.

3. Field tests under typical user conditions.

4. Tests for compliance to standards, when applicable.

The normal result of this experimental testing is a series of relatively minor changes so that the product meets original specifications, has good life and operates safely and reliably. After these design changes have been proven, the product is released for production.

Production Engineering

When a product reaches the production stage, all engineering has not been completed but a new phase of engineering has been begun. Production Engineering is concerned with manufacturing methods, cost reduction, quality assurance, reliability analysis and minor product redesign to meet changing requirements.

These activities are normally ongoing for the useful life of the product in active production. A change to add a new sales feature, for example, might adversely affect reliability and require another change.

Other Considerations

In most engineering settings, there will be people specialized in each of the areas of product development. One engineer will work only in production, while another will work only in concept development.

There are also a variety of services that consumers have come to expect and that may have engineering involvement. These are 1.) written operating instructions, 2.) maintenance manuals, 3.) formal warranties, and 4.) repair and general service.

REHABILITATION ENGINEERING

Rehab. Engineers are found working in many areas of the Design Process, often working in several areas sequentially; however, there are significant differences in intensity of effort.

Identification of Need

A Rehab. Engineer is not normally involved at this stage. Physicians and Rehab. Professionals, in conjunction with a client, describe the fundamental problem based on their understanding of what an engineer might accomplish. The engineer is then called in as a member of the Rehab. Team.

Exploration

The Rehab. Engineer would normally begin work at the exploration phase. He/she would study other work done of a similar nature and gather more information when required. This phase could include mathematical models or physical models, as in other engineering, but it is not as common because of the high cost per ultimate user. In general, there is a scarcity of information related to Rehab. Engineering and this affects the outcome of the phase.

Concept Formation

The Rehab. Engineer would probably formulate a concept and present descriptions and sketches to the Rehab. Team for review. If the concept was not a "success", then the process would be repeated.

Product Development

After the concept is approved, our Rehab. Engineer would probably design and fabricate an "experimental" unit. "Experimental" may not be the best word choice because it may not be perceived as experimental by the Rehab. Engineer even though it would be to others. If testing shows that it is successful, then that would become the "final product."

A decision might be made to take the experimental design into production but this is not necessarily the case. The consideration of the design for production would be of a whole new problem requiring new exploration, different concepts, and a design based on multiple production considerations.

PROBLEM DISCUSSION

A Rehab. Engineer's "final product" would probably be called an "experimental" device by other types of engineers. The device would have undergone functional testing but not failure, reliability, and field tests. There would probably not be design or safety standards to meet, given the nature of the device, and there may not be formal provisions for instructing the users, maintenance and prepare of the device.

It is important to consider what might happen if the device failed and someone was injured.

The injured party would probably seek compensation based on product design defect. The basis for this claim would be that:

> "the design process was inadequately performed, a step was skipped (e.g., there was no product testing which would have uncovered the problem) or no design process was followed at all." (6)

There are many questions that must be answered:

1. Are there, or should there be, any legal differentiation between Rehab. Engineers and other engineers? Between their products?
2. Is it reasonable or even possible to test a device for a unique application?

3. Who should pay for extensive (read expensive) testing when it is required?

RECOMMENDATIONS:

Any organization providing Rehab. Engineering services should be aware of the problem discussed here. The following suggestions are made to help address the problem, both from an individual and a collective standpoint.

1. Modify the definition of a "Rehab." Engineer (or develop a new designation) to reflect the fact that most work is for unique application. This implies, then, that the engineer who designs a commercial product, even if it is for rehabilitation, is a Product Engineer.
2. Treat all these unique products as experimental. Inform users through appropriate means that the devices are experimental and that they are performing "field testing" in using the device.
3. Request follow-up information on devices so that as much information as possible can be gathered and used to advantage in future designs.
4. Inform the user of warranties and of service arrangements, and provide written instructions.
5. Seek legal counsel before developing a plan for providing engineering service to the disabled community.

REFERENCES

1. D. Henry Edel, Jr., Editor, Introduction to Creative Design, Prentiss Hall, 1967.
2. George C. Beakley and H. W. Leach, Engineering: An Introduction to a Creative Profession, 4th edition, McMillan Publishing Company, 1982.
3. Joseph P. Vidosic, Elements of Design Engineering, Ronald Press Company, 1969.
4. John C. Gibson, Introduction to Engineering Design, Holt Rinehart Winston, Inc., 1969.
5. Peter Gasson, Theory of Design, Harper and Row Publishers, Inc., 1973.
6. Richard F. Schaden and Victoria C. Heldman, Product Design Liability, Practicing Law Institute, 1982.

SPONSORING AGENCY

Curative Rehabilitation Center
9001 West Watertown Plank Road
Milwaukee, Wisconsin 53226

15.9P

DELIVERING A SPECIAL SERVICE

Jane L. Mills, M.A.
United Cerebral Association of San Diego, CA
Jayne C. Higgins, M.A.
California Avenue School, Vista, CA

ABSTRACT

This paper focuses on the non-oral person as a communicator. It addresses the need to provide appropriate training to insure the successful interaction of the non-oral communicator in the world. This occurs through a process called "environmental training" which is to clearly evaluate and match those skills required by the environment with those skills attained by the client. The training focuses on the "skill discrepancy"(7). Creative, stimulating, adaptable, and preference based environments were also important to the training process. Other specific rationale and strategies are discussed. "Environmental training" is presented as an important key to "linking the equipment, the client and the environment," in successful interactions.

INTRODUCTION

Success during the assessment stage of matching the non-oral person to the appropriate communication prosthesis does not necessarily mean success for that person as a non-oral communicator. The crucial link seems to be based in the training process. Our specialty in service delivery is "environmental training."

"Environmental training" is accessing the client's important worlds and significant others. It is clearly evaluating the present interactive process in that environment and training the client to use a non-oral communication system to streamline that interaction, to make communication somewhat more "universal and less idiosyncratic"(5). In the process we train an environment to adapt to the non-oral speaker and to become "communicatively accessible. For an environment to be "communicatively accessible", there is a successful link between equipment, client and the receiver of information"(4). To insure optimum interaction the equipment is easily comprehended, the client is able to use it efficiently with few errors, and the environment has a high degree of tolerance and adaptability. Through an "environmental training" process these conditions can be created and communication can flourish.

We fear all too often that this type of training is given lip service, is thought of as a "frill". Our experience has shown that it can mean the difference between a competent communicator who can advocate for himself, and a failure. It is also our belief that persons or institutions supplying the assessments, prescriptions, and devices must also accept responsibility for insuring that appropriate training occurs.

METHODOLOGY

In this approach to train the use of a non-oral communication prosthesis, we first focus on the mechanics of this particular system. We teach answers to questions like "How does it turn on and off?" "What if I make a mistake, how do I correct it?" "What if the listener doesn't understand?" Strategies to clarify are included: repeating, adjusting the volume, using a pen light, choosing clearer pictures, adding vocabulary, adding listener directions, saying it a different way, etc. In general, mechanical training focuses on how this system works in and how it can be adapted to specific environments.

The second component of training is interactive. The client is observed in the important environment interacting with significant others. We note the breakdown and barriers to a more universal form of communication. Then the building and expanding process beings. It is important to note building and expanding rather than "re-do and replace". The present system of communication is working to some degree and may be given a high comfort rating by the user.

It's wise to slowly expand the existing system into the new one, always with the end product being a more universally understood communication system(5).

TECHNIQUES

Some training strategies include:

1. Experience, simulate and/or brainstorm about the link-up of equipment, client and environment.

2. Evaluate the environment as to its "communication accessibility".

   ___ Environmental tolerance
   ___ Environmental adaptability
   ___ Environmental familiarity

      ___ with the communicator
      ___ with the system

   ___ Number of listeners
   ___ Comprehension of system in the environment
   ___ Ease of message completion

3. Evaluate the client's attained skills and those skills required by the environment(7). Note the discrepancies between the two.

4. Solve the "competence discrepancy" with more mechanical changes, if possible, and most often with exact training of those required skills in the environment(7). (Home, school, work, leisure.)

5. Use of behavior shaping techniques, including setting barriers to encourage generalization and spontaneous expression.

6. Evaluate attitudes and how they might be affecting training. Attitudes of the client and significant others are directly correlated with the success or failure of the training.

7. Providing a motivating, stimulating, preference based environment is another vital component to the training.

8. Use of a "buddy system" is helpful. It provides appropriate modeling and the "buddy" can act as a communication facilitator. Usually, fairly soon, someone in that natural environment takes on the job of communication facilitator. This is true environmental adaptability.

9. A last strategy is to learn from the successes and failures.

SUMMARY

Our belief is that the key to successful communication with non-oral systems will be in having highly skilled users with environmentally appropriate systems who are self-advocates.

How do they get there? With our help in delivering services that include a creative and strong environmental training component.

RESOURCES

(1) Barker, Peggy, Children's Hospital at Stanford Rehabilitation Engineering Center, 520 Willow Road, Palo Alto, CA 94304.

(2) Cook, A., and Coleman, C., "The Development of a Delivery System for Assistive Devices," Status Report, January 1980, Assistive Device Center, California State University--Sacramento, Sacramento, CA.

(3) Eulenberg, John, Communication Outlook, Artificial Language Laboratory, Computer Science Department, Michigan State University, East Lansing, Michigan.

(4) Hagan, Chris, "Assistive Communication Systems: A Rationale for Their Use, Selection and Application," International Seminar on Non-Vocal Communication, Swedish Institute for the Handicapped, Broma, Sweden, April 1977.

(5) MacDonald, James, Language Through Conversation," Parent-Child Communication Project, Nisonger Center, Ohio State University, Columbus, Ohio 43210.

(6) Montgomery, Judy, Non-Oral Communication: A Training Guide, 1980, Plavan School, 9675 Warner Avenue, Fountain Valley, CA 92708.

(7) Pumpian, Ian, Lecture delivered at United Cerebral Palsy, San Diego, Spring 1982.

(8) Vanderheiden, G. and Grilley, K., Non-Vocal Communication Technical Aids for the Severely Physically Handicapped, Baltimore, University Park Press, 1976.

Mills & Higgins Speech Pathology Associates
301 Village Run East
Encinitas, CA 92024

15.10P

INFORMATION DISSEMINATION AND SERVICE DELIVERY

Jolan Cossairt
University of Michigan
Rehabilitation Engineering Center
Ann Arbor, Michigan

ABSTRACT

Service delivery at the University of Michigan Rehabilitation Engineering Center is aimed primarily at the professional community of persons working in the area of personal licensed vehicles for the disabled. The primary medium for this activity is information dissemination, both written and spoken. These two types of information dissemination as used at the University of Michigan Rehabilitation Engineering Center are described in this paper.

INTRODUCTION

The need for improved information dissemination and communication techniques within the rehabilitation community has been noted by researchers, service providers and consumers. The quality of service delivery correlates highly with the quality of information dissemination and communication between members of the rehabilitation community themselves and with those they serve.

Rehabilitation professionals come from many academic disciplines. Because of this the rehabilitation literature is scattered throughout the professional literature of many fields, notably medicine, engineering and education. In addition to the professional literature, a vast amount of consumer-oriented literature exists. There is also important information in the catalogs and brochures of manufacturers of adaptive equipment for the handicapped.

It then seems quite obvious that the initial step in any information dissemination-communication-service-delivery network is to bring together the relevant literature. At the University of Michigan Rehabilitation Engineering Center (UM REC) where the focus is personal licensed vehicles for the disabled, the professional literature in the area has been collected and catalogued in the library collection of the University of Michigan Transportation Research Institute (UMTRI) while the product literature and selected consumer literature is housed in the UM REC. The professional literature circulates according to the University Library policies while the materials at the UM REC are primarily for in-house use.

PUBLICATIONS AND PRESENTATIONS

All publications of the UM REC are transmitted to the National Rehabilitation Information Center (NARIC) in Washington and to the National Clearing House of Rehabilitation Materials in Stillwater, Oklahoma. Both organizations disseminate their holdings to interested persons. In addition NARIC provides a number of reference services. The ABLEDATA data base of rehabilitation product information is also housed at NARIC. Information on adaptive automotive equipment was supplied by this REC.

All federal grantees prepare an annual report of their research accomplishments. This report of the UM REC along with specialized reports of certain research activities and a Newsletter, the UM RECorder, form the bulk of the materials distributed by the UM REC. The annual Activities Report contains detailed technical information about research activities while the specialized reports provide in-depth descriptions of the study methods and results of particular activities. The UM RECorder is written in a lighter style and is directed to an audience interested in a less detailed presentation of our research results. Significant findings from individual research activities are submitted to professional refereed journals for publication.

Participation in the annual meeting of the Rehabilitation Engineering Society of North America (RESNA) affords varied means of communication with both professional colleagues and consumers. An exhibit of UM REC research projects highlights some of those activities. Staff members are present to answer the questions of those who visit the booth. An Advanced Topical Discussion, devoted to Personal Licensed Vehicles for the Disabled, provides for a lively interchange between researchers, rehabilitation personnel and consumers. Our researchers are also encouraged to prepare papers for the technical sessions of RESNA and the UM REC is well represented during these sessions. RESNA provides a year-round informal channel of communication for staff members who serve on RESNA committees.

Other presentations are regularly made by members of the UM REC staff in the course of a year. The UM REC is represented each year among the presentations at the Annual Meeting of the Transportation Research Board. During the International Year of Disabled Persons, a number of staff members made presentations at the Rehabilitation Institute of Chicago during the International Symposium on Independent Life in recognition of the International Year of Disabled Persons in 1981. In 1980 and again in 1982 UM REC staff participated in a Workshop Conference on Driving for the Physically Handicapped also at the Rehabilitation Institute of Chicago.

Presentations on Wheelchair Tie-downs and Restraint Systems for Handicapped Persons are given to diverse groups. They range from a presentation to the Physical and Occupational Therapists in nearby Oakland County, Michigan to an International Symposium on Occupant Restraint in Toronto. Attendees at such meetings can communicate concerns from consumers and parents to the research community. Staff members are also encouraged to make presentations at their professional specialty meetings.

Some professional organizations have specialty publications directed to the specific interests of their groups. One of these groups is the Physical

Disabilities Specialty Section Newsletter of the American Occupational Therapy Association. They contacted the UM REC for an article on wheelchair restraint systems, which we supplied. Several thousand occupational therapists especially interested in the problems of persons with physical disabilities now know of the UM REC and its work.

Before funding was cut in the area of human services, the Center for Continuing Education of RSA Region V published Continuing Education News for rehabilitation counselors in Region V. We proffered and they accepted an article on Wheelchair Restraint Systems as a followup to an article on Adaptive Driving in an earlier issue of Continuing Education News. This article reached rehabilitation counselors in the 6-state area of the region.

DEMONSTRATION VAN

In 1979 the UM REC purchased a multipurpose van. It was equipped with a Ricon side-door lift, reduced effort steering, a servo control unit from Creative Controls, Inc. (CCI) and a restraint system from CCI. This van was intended to be used for a display van as well as for a research vehicle. In 1979 at an Independent Living Conference in Cleveland, a UM REC staff member was in the van. Disabled consumers entered the van using the lift and once in the driver's position (the regular driver's seat had been removed), they were allowed to operate the servo control and the reduced effort steering. This gave some who previously believed they did not have sufficient strength for driving the encouragement to seek an evaluation for driving. No followup was made so it is not known when any of the group undertook a driver education program.

The van was also displayed at the International Conference on Rehabilitation Engineering in Toronto in 1979 with emphasis on the wheelchair restraint system from CCI. Staff members from CCI were present and communication and feedback were impressive. One of the reasons for the impressive feedback was that the exhibition area was open to the public for one evening. Parents, youngsters in wheelchairs, teachers, and interested or just curious persons could come through the exhibit area.

The van was taken to the International Symposium on Independent Life in Chicago where it was on display at the Rehabilitation Institute of Chicago with several other vans. Researchers, driver educators, and consumers had a unique opportunity to see various equipment side by side.

Locally, the van has been demonstrated for the REC staff, the University Hospital staff, a workshop for Secretary of State personnel as well as for the annual conference of the Association of Driver Educators for the Disabled. The driver educator on the REC staff demonstrated the van to Michigan driver education teachers at the Michigan Driver and Traffic Safety Association meeting.

SEMINARS

In June of 1981 the UM REC conducted a seminar for personnel associated with the Office of the Michigan Secretary of State. The state-of-the-art of driver evaluation, education, and adaptive driving equipment and systems for persons with disabilities included a hands-on demonstration with a variety of equipment from nearby rehabilitation centers. This seminar was planned with the assistance of the Office of the Secretary of State. Further workshops for other persons involved in the area of personal vehicles for the disabled were planned; however, budget restrictions on travel for the proposed audiences made it necessary to suspend plans for further seminars.

ADVISORY COMMITTEE

An Industry-Rehabilitation Community Advisory Committee was established to encourage communication between consumers and manufacturers and distributors of assistive driving equipment. Members of the Committee include representatives of the major automobile manufacturers and firms producing modified vehicles and adaptive automotive equipment. Representatives of consumer organizations such as the Paralyzed Veterans of America were also invited. The mission of this Committee is to provide feedback that will guide the UM REC and its research endeavors and priorities.

ACKNOWDLEGEMENTS

This research was supported by Grant #G008005816 and Grant #G008200047 from the National Institute of Handicapped Research, Department of Education, Washington DC.

ADDRESS

University of Michigan
Rehabilitation Engineering Center
208 Lay Automotive Laboratory
Ann Arbor MI 48109

15.11P

VOCATIONAL REHABILITATION OF A C-2 QUADRIPLEGIC

Charles J. Laenger, Sr.
Rehabilitation Engineer
Tulsa Rehab Center
Tulsa, Oklahoma

Gerald Davis, Counselor
Oklahoma Department of
Rehabilitative Services
Tulsa, Oklahoma

Karen Griffin, O.T.R.
Occupational Therapist
Tulsa Rehab Center
Tulsa, Oklahoma

ABSTRACT

Ray Murphy became a C-2 quadriplegic twelve years ago. He and his family were unaware of the independence that technical devices can bring, so he was unable to exert any control over his environment for eleven years. Today he effectively operates an environmental control system, powered wheelchair and Apple II computer with puff-sip control. He is now a client of Oklahoma Department of Rehabilitative Services and expects to continue studies in computer science in the near future. This paper describes technical intervention and most productive interaction between the private sector and a state vocational rehabilitation agency.

INTRODUCTION

Ray Murphy lay in a circle bed for eleven years where he was unable to exert any control over his environment. The local rehabilitation agency could not legally open a case on this man because he did not exhibit "reasonable vocational potential". Fortunately, a friend and fraternity brother contact the IMPART program and the Rehabilitation Engineering Center at the Tulsa Rehabilitation Center[1] Subsequently, a local fund drive resulted in the collection of $21,000 for environmental control and other equipment that improved Ray Murphy's quality of life and enhances his employability.

Figure 1. Ray Murphy lay in circle bed for eleven years - unable to exert any control on his environment. Note respirator in foreground.

Figure 2. Puff-sip control is used for the environmental control, Apple II computer and MED Quad Wheelchair.

BACKGROUND

Upon graduating from college with a B.A. in Business, Ray Murphy broke his neck while wrestling. He had been an excellent student and athlete having won second place in the N.C.A.A. national competition in 1971. After several months in an acute hospital, he returned home where he has received excellent care by his parents and a devoted neighbor-friend. He has a tracheostomy, a stationary respirator and has been in a circle bed since the onset of his disability. He and his family were resigned to this quality of life and state of existence. A friend believed that technology could help. He contacted the rehabilitation engineer at the Tulsa Rehabilitation Center who formulated a preliminary plan for prescription and application of assist and mobility devices. Funds for equipment were acquired and work began.

MATERIALS AND METHODS

A MicroDec environmental control system with puff-sip control was acquired and installed in the home. A therapist from the Tulsa Rehabilitation Center visited in the home and instructed Mr. Murphy in its use.

A MED Quad wheelchair with puff-sip control, reclining back and portable respirator was acquired. A MED Puff-Sip Wheelchair Control Simulator was loaned to the patient two months prior to delivery of the chair in order for him to develop sufficient respiratory function and control for driving the powered wheelchair. Transfer from the manual wheelchair and non-portable respirator

Figure 3. Transfer to the powered chair required assistance of respiratory specialists.

to the electric powered wheelchair with portable respirator was accomplished with the assistance of a respiratory physician and respiratory technicians.

With advice and technical assistance of the Northwestern University REC, an Apple II computer with puff-sip interface was acquired. Cursory trials indicated that Mr. Murphy could easily operate the computer with this system. Rehabilitation engineering personnel of the Tulsa Rehabilitation Center advised the state vocational rehabilitation agency that this man had demonstrated employment potential and requested that his eligibility for services be reviewed.

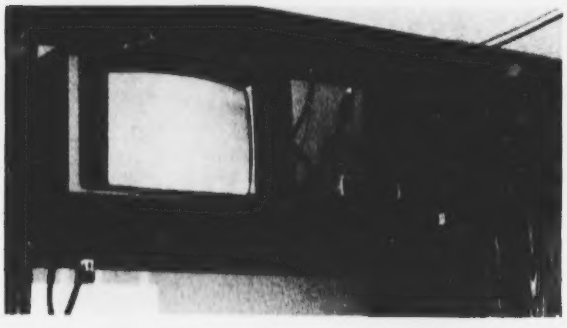


Figure 4. The MicroDec and T.V. control were mounted for convenient viewing. The Apple Computer was mounted on a special cabinet.

Oklahoma Rehabilitative Services subsequently opened a case on Mr. Murphy and began providing vocational rehabilitation counseling services. A tutor was sent to the home to provide instruction on use, operation and introduction to programming of the Apple II computer. After thirty one-hour sessions, it was concluded that the client was ready for formal college courses in computer science. The counselor and client agreed that the vocational objective, a mandatory part of the rehabilitation program plan, would be income tax preparation, computer analyst and statistician.

Mr. Murphy was further examined by a pulmonary function specialist at Hillcrest Medical Center who prescribed special incentive treatments that resulted in significant improvement of his ability to breathe without assistance. He can now function without assistance for four hours. Six months ago, he could breathe without assistance for five minutes only.

FURTHER ATTEMPTS TO INCREASE DATA HANDLING SPEED

In an attempt to increase "writing" speed, Mr. Murphy was provided a Cypherlog device which converts international code (Morse Code) to ASCI II code. The Cypherlog generates suitable video information which is fed into the input of a television monitor where the selected characters are displayed. It was concluded after several trials, that the Northwestern NUCDC program best suited his needs for "writing" and addressing the Apple II computer.

Figure 5. Even after eleven years of immobility, Ray learned to control the puff-sip wheelchair very quickly.

Figure 6. Sponsored by Oklahoma Department of Rehabilitative Services, Ray will resume study of computer science in a college classroom setting.

DISCUSSION

Vocational rehabilitation engineers have demonstrated countless times that the quality of life and employability can be enhanced through utilization of technical devices. It appears that this is a never-ending role of the rehabilitation engineer. It indicated, quite clearly, that more work must be done to educate consumers, third-party payers and other rehabilitation professionals.

CONCLUSIONS

Better means for evaluating the vocational potential of severely disabled individuals must be implemented by state agencies. In order for this to occur, evaluation departments or centers will require an array of communication, environmental control and mobility devices. Evaluators will have to learn to use this equipment; an alternative will be to accept the recommendations of therapists, and rehabilitation engineers. Timely and appropriate evaluation could have caused Ray Murphy's rehabilitation program to begin 10 year earlier!

Ray Murphy plans to study computer science at Tulsa Junior College in the spring of 1983. He probably will achieve employability as a self-employed income tax service person or as a statistician. There is absolutely no doubt that the quality of life of Ray Murphy and the quality of life of his family have been dramatically improved. If Mr. Murphy becomes self-employed and financially self-sufficient at the age of 36, in all likelihood he will return more tax dollars to the public coffers than he ever received. Even if he doesn't, we would be fools not to have participated in this magnificent effort.

REFERENCE

1. The IMPART program was sponsored by NIHR Grant No. G008003085 which has terminated. Nevertheless, a modified IMPART program continues in Oklahoma.

ACKNOWLEDGEMENTS:

Craig Heckathorne of the Northwestern University REC provided valuable technical advice. The Northwestern NUCDC program loaned a Nu-Apple Interface and special programs which continue to be used by Mr. Murphy. Margaret Pfrommer of Northwestern also provided valuable advice and encouragement.

Gerald Tumbleson and other administrators of Oklahoma Department of Rehabilitative Services exhibited fortitude, leadership and good judgement when this agency certified Mr. Murphy for services. This case represents another successful interaction between the public and private sector.

The private sector in Oklahoma responded to fund drives by providing $21,000 for assist devices and $11,000 for a special van. These contributors deserve credit and praise. However, it must be reiterated that cost and time-effective rehabilitation programs must not rely on fund drives. Refer to "Development of Community Resources For Rehabilitation - A Solution To Money Problems?" 5th Annual Conference On Rehabilitation Engineering 1982.

Finally, note that almost all of the equipment used to rehabilitate Ray Murphy was developed at least in part, by programs sponsored by the National Institute of Handicapped Research.

Charles J. Laenger, Sr.
Director
Rehabilitation Engineering
Tulsa Rehabilitation Center
1125 S. Trenton
Tulsa, Oklahoma 74120

TOWARDS A THEORETICAL FRAMEWORK OF SERVICE DELIVERY

Ron Levy

Groupe de Recherche en Socio-Technologie de l'Adaptation
Faculté de l'Aménagement, Université de Montréal.

INTRODUCTION

The scope of this paper is to outline an accessible paradigm for (re)habilitation and to situate within it the 'instrument' of service delivery. It is hoped that through this process of creating a contextual theoretical framework to the activity of service delivery it may be possible to illustrate the spectrum of interconnected elements that need to be taken into account. The theoretical framework is derived from a general concept of paradigmatic models and a concept of paradigmatic fields. The fields identify the underlying structure of (re)habilitation and four such fields are postulated: The epistemological field, the ontological field, the methodological field and the field of intent. Service delivery will be shown to be part of the ontological field of the paradigm. It will also be shown that service delivery should not be viewed as an isolated instrument of the process of (re)habilitation, but rather in terms of a larger whole of (re)habilitation theory, (re)habilitation methodology and the paradigmatic subject of the adapting individual.

BACKGROUND

A General Paradigmatic Framework

It is generally accepted that a paradigm (1), at its most fundamental level, is a way of looking at the world. It may also be said that each individual, as indeed each scientific discipline, has a particular way of viewing the world; their particular paradigm. On the face of it, this may appear to be a rather simplistic definition, so in order to make the concept of a paradigm more intelligible it is proposed that, a paradigm is made up of four interrelated paradigmatic fields:

a) An image or set of images of the world, or an ideology constituting a set of general ideas or a philosophical program - the Epistemological Field.
b) A set of contextual artefacts or instruments which constitute the substance of 'things' encompassed by the paradigm - the Ontological Field.
c) An operational program which constitutes the actions derived from reflection (e.g. ideology) and performed using the appropriate instruments, with a view of acquiring knowledge or information about a certain subject matter - the Methodological Field.
d) The subject matter or area of study, intent, inquiry or mediation. It is that archetypal world or part thereof on which the paradigm operates - the Field of Intent.

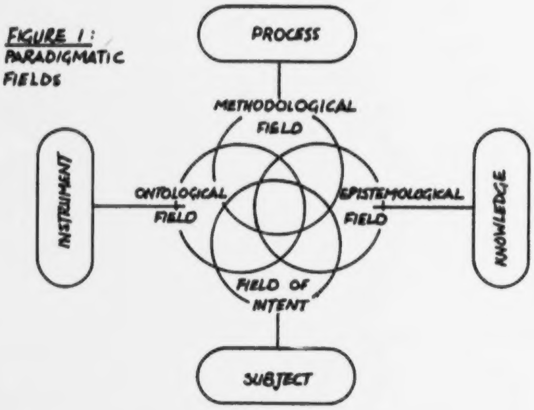

PROCESS
METHODOLOGICAL FIELD
INSTRUMENT
ONTOLOGICAL FIELD
EPISTEMOLOGICAL FIELD
KNOWLEDGE
FIELD OF INTENT
SUBJECT

FIGURE 1: PARADIGMATIC FIELDS

A Systemic Paradigm of (Re)habilitation

Without going into the philosophical details of each of the above paradigmatic fields, it is possible to postulate a paradigm for (re)habilitation based on this general model. (Re)habilitation can be described in terms of a set of four interacting fields: The field of (re)habilitation theory, the field of (re)habilitation process, the field of (re)habilitation instrumentality and finally the field of (re)habilitation intervention.

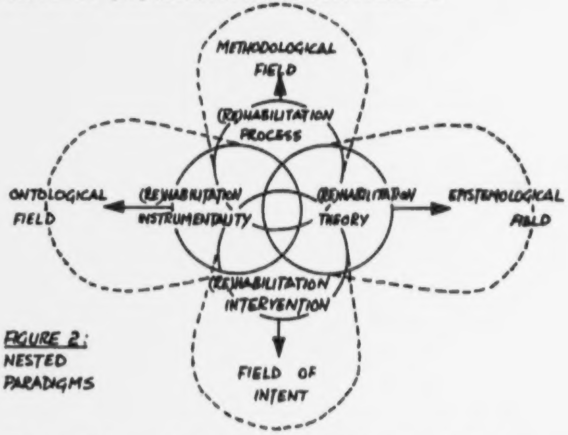
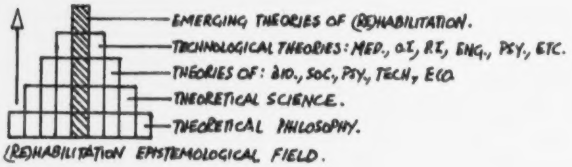
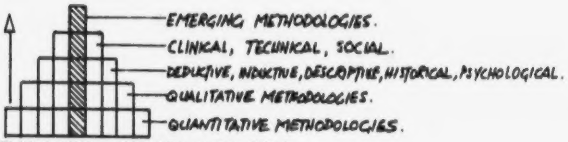

METHODOLOGICAL FIELD
(RE)HABILITATION PROCESS
ONTOLOGICAL FIELD
(RE)HABILITATION INSTRUMENTALITY
(RE)HABILITATION THEORY
EPISTEMOLOGICAL FIELD
(RE)HABILITATION INTERVENTION
FIELD OF INTENT

FIGURE 2: NESTED PARADIGMS

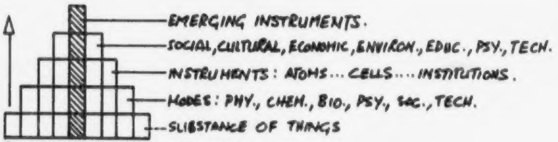
This model can be described further by defining each of the four paradigmatic fields in (re)habilitation in terms of rooted layers of ordered elements.

FIGURE 3:

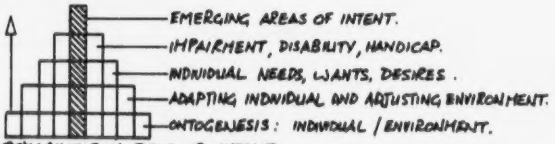

EMERGING THEORIES OF (RE)HABILITATION.
TECHNOLOGICAL THEORIES: MED., O.T., R.T., ENG., PSY., ETC.
THEORIES OF: BIO., SOC., PSY., TECH., ECO.
THEORETICAL SCIENCE.
THEORETICAL PHILOSOPHY.
(RE)HABILITATION EPISTEMOLOGICAL FIELD.


EMERGING METHODOLOGIES.
CLINICAL, TECUNICAL, SOCIAL.
DEDUCTIVE, INDUCTIVE, DESCRIPTIVE, HISTORICAL, PSYCHOLOGICAL.
QUALITATIVE METHODOLOGIES.
QUANTITATIVE METHODOLOGIES.

(RE)HABILITATION METHODOLOGICAL FIELD.


EMERGING INSTRUMENTS.
SOCIAL, CULTURAL, ECONOMIC, ENVIRON., EDUC., PSY., TECH.
INSTRUMENTS: ATOMS... CELLS.... INSTITUTIONS.
MODES: PHY., CHEM., BIO., PSY., SOC., TECH.
SUBSTANCE OF THINGS

(RE)HABILITATION ONTOLOGICAL FIELD.


EMERGING AREAS OF INTENT.
IMPAIRMENT, DISABILITY, HANDICAP.
INDIVIDUAL NEEDS, WANTS, DESIRES.
ADAPTING INDIVIDUAL AND ADJUSTING ENVIRONMENT.
ONTOGENESIS: INDIVIDUAL / ENVIRONMENT.

(RE)HABILITATION FIELD OF INTENT.

Instruments of (Re)habilitation

The ontological field of the (re)habilitation paradigm is the envelope of those "things", those real or existing objects, entities or environments, which constitute the instruments of operation of (re)habilitation. These instruments range from physical tools at one level, to political movements or social entities at another. In any form of praxis, where reflection (i.e. knowledge, theory, ideology) is coupled with action (i.e. process, operation) to achieve certain goals or to mediate in a particular state of affairs, it is necessary to intervene with the aid of specific instruments. A methodology is primarily a procedure for doing something, but it does not necessarily include the instrument, the 'probe', for executing the activity. Thus the ontological paradigmatic field is a collectivity of instruments used in the praxis of (re)habilitation. A certain number of these instruments would make up what can be called, service delivery in (re)habilitation.

Using the broad definition of instruments mentioned above, the collection of instruments that make up a service delivery program could range from physical objects, to human organizations, to computer simulations, to educational seminars, to environmental situations, to political expediencies and so on. In other words they are instruments emanating from social, cultural, political, economic, educational, psychological, ecological and technological spheres. The paradigmatic activity of service delivery in (re)habilitation is then the praxis of the epistemological and methodological fields using the agents of the ontological field on and with the field of intent.

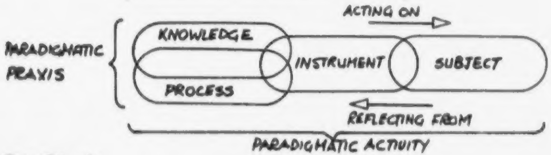

PARADIGMATIC ACTION
ACTING ON
PARADIGMATIC PRAXIS
KNOWLEDGE
PROCESS
INSTRUMENT
SUBJECT
REFLECTING FROM
PARADIGMATIC ACTIVITY

FIGURE 4:

DISCUSSION

Service Delivery in (Re)habilitation

The systemic view of any particular instrument used in (re)habilitation is a view that is not frozen onto one focal point. To consider the phenomenon of service delivery merely as a mechanism for the dispensation of goods and services by one group of people to another, is a fallacy of the first order. Service delivery whilst being classified as a part of the ontological field, or as one of the instruments of (re)habilitation, must also be viewed as being very much part of the notions and exigencies of individual adaptation and environmental adjustment(2). In addition, one cannot exclude service delivery concepts from the theoretical or ideological imperitives of adaptation. It is also nonsensical to view service delivery without the fundamental concerns of methodology and the operationality of the delivery program itself.

The service delivery of, say, technical aids, also depends to a large extent on the overriding technological imperitives of the society(3). Whilst these imperitives are technical in nature they are also greatly influenced by biological, psycho-social and ecological concerns. The thrust of service delivery of technical aids may be technological, however, the context of this thrust is influenced by a wide range of other diverse instruments and other paradigmatic fields. In this way the technological imperitives are seen to manifest themselves in terms of how technology is used, in the operations to implement overall goals, in the knowledge structures of (re)habilitation and in terms of the subjects on which and with which the technology is to be implemented.

If one accepts that the provision of a technical aid which meets the needs of, and is acceptable to the disabled individual and his/her entourage is a complex set of activities, then one must identify the structure of this complexity and use it to create a greater awareness of service delivery as a phenomenon. Take, for example, the relationship between methodology and ontology as it concerns service delivery, and ask the question - how does the process of evaluation (inherent in methodological concerns) influence the ontological instrument of service delivery?

In reply, one may say that evaluation procedures are directly related to decision making(4), to referral of users to the program, to the identification of user's needs, to the establishment of individualized programs to attain specific goals, and to the decision as to what kind of technical aid(s) is required (if at all). In addition there is the evaluation of the user within his/her program with the technical aid and the functional and technical assessment of such a situation. This leads to the evaluation of the user once he/she leaves the program and continues in the community (follow-up evaluations) and of course to evaluation of the whole service delivery program itself. It is evident that effective service delivery is impossible without multiform evaluation procedures and they may be summarized as follows:

User Needs Evaluation
Clinical Evaluation
Technical Evaluation
Community Evaluation (follow-up)
Program Evaluation

If one now goes back to the four paradigmatic fields of (re)habilitation, service delivery (the instrument) and evaluation (the methodology) assume wider perspectives when viewed as an interconnected set together with the fields of knowledge and intent.

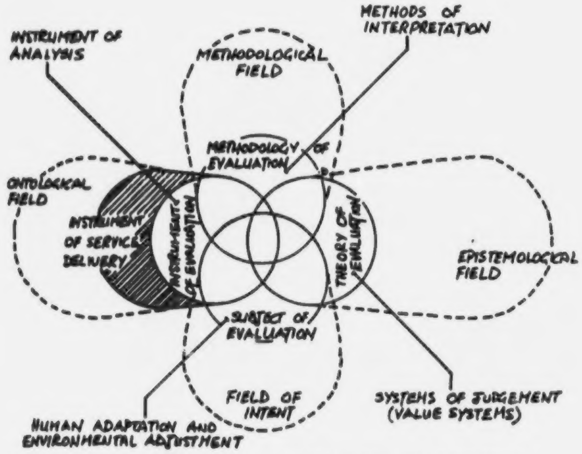

METHODS OF INTERPRETATION
INSTRUMENT OF ANALYSIS
METHODOLOGICAL FIELD
METHODOLOGY OF EVALUATION
ONTOLOGICAL FIELD
INSTRUMENT OF SERVICE DELIVERY
INSTRUMENTS OF EVALUATION
THEORY OF EVALUATION
EPISTEMOLOGICAL FIELD
SUBJECT OF EVALUATION
FIELD OF INTENT
SYSTEMS OF JUDGEMENT (VALUE SYSTEMS)
HUMAN ADAPTATION AND ENVIRONMENTAL ADJUSTMENT

FIGURE 5: PARADIGMATIC MODEL OF SERVICE DELIVERY EVALUATION :

From a paradigmatic point of view the notion of service delivery in (re)habilitation is one which must derive some of its fundamental characteristics from the methodological activity of evaluation. For example, the raison d'être in (re)habilitation for service delivery is to help achieve individual adaptation and environmental adjustment. In addition the influence of evaluation underlines three other areas of some importance:

a) The instrument of service delivery evaluation would be concerned with bringing order to data and organizing information into patterns and categories, i.e. analysis.
b) The methodology of service delivery evaluation would focus on the means of attaching meaning and significance to the analysis, i.e. interpretation.
c) The theory of evaluation in service delivery would involve the understanding of how to assign value to what has been analysed and interpreted, i.e. judgement.

Space does not permit further discussion of these three fundamental evaluation characteristics and their influence on the function of service delivery. However, the concepts of methodological procedures for equitable interpretation of the analysis of data is obviously of vital concern. In addition the establishment of clear theories of value systems to allow judgements to be made are at the very core of achieving effective service delivery programs assuring appropriate and meaningful outcome for all concerned(5).

CONCLUSION

This very brief and somewhat parsimonious view of a systemic paradigm of (re)habilitation has tried to show the interconnectivity of each of the component matrices of (re)habilitation. This paper has underlined the essential and fundamental requirement for a general conceptual framework; a paradigm for (re)habilitation. Through this paradigm it is possible to identify the various facets of (re)habilitation, their containment, their ideological interrelationships, their methodological linkages, their instrumentalities and their mutual subjects of mediation.

It is also suggested that the (re)habilitation field is in the process of what can be called a paradigmatic transition. This is true not only of (re)habilitation but of scientific enquiry as a whole. It is a basic change of attitude to our study of human affairs that is being reworked. It is thus imperitive that diverse views of (re)habilitation be studied, general models proposed, approaches developed, procedures tried, so that the transition can be achieved. What must be emphasized however, is the overriding tenet that the new paradigmatic view of (re)habilitation is intergrative, interacting, interconnected and systemic.

The systemic analysis of service delivery in (re) habilitation has been shown to be not a simple mechanistic breakdown of system functions, but rather a helical passage through its contextual paradigm, a process akin to gestaltism and functional analysis combined. It is firmly believed that only when the systemic view of (re)habilitation is well understood will the transformation of (re)habilitation take place from being "the third phase of medicine", locked into the deterministic medical model, to a fully fledged discipline dealing with the intentionality of human adaptation, based on its own model of (re)habilitation or more appropriatly, its own model of adaptation.

REFERENCES

1. Battista, J.R., (1977), "The Holistic Paradigm and General System Theory", General Systems, Vol. XXII, 65-71.
2. Kleinman, B.L., and Bulkley, B.L., (1982), "Some Implications of a Science of Adaptive Responses", The American Journal of Occupational Therapy, Vol. 36, No. 1, Jan., 15-19.
3. O.T.A., (1982), Technology and Handicapped People, Office of Technology Assessment, Congress of the United States, Washington, D.C.
4. Patton, M.Q., (1980), Qualitative Evaluation Methods, Sage Publications, Beverly Hills.
5. Keilhofner, G., (1982), "Qualitative Research: Part I & II", The Occupational Therapy Journal of Research, Vol. 2, No. 2,3.

ADDRESS

Faculté de l'Aménagement, Case Postale 6128,
Succursale 'A',
Université de Montréal, Montréal, Québec, Canada
H3C 3J7

15.13P EFFORTS TO VOCATIONALLY REHABILITATE A TETRAPLEGIC CLIENT

C. J. Laenger, Sr.
Rehab Engineer
Tulsa Rehab Center
Tulsa, Oklahoma

Debbie Hill,M.S.C.C.
Speech Pathologist
Tulsa Rehab Center
Tulsa, Oklahoma

Rex Jones
Elec. Instr.
Okla. State Tech
Okmulgee, Okla.

D.V.Cockburn
R.N.
Okmulgee Rehab
Okmulgee, Okla.

ABSTRACT

Functional capabilities of a very severely disabled individual were significantly improved through prescription, application and training with technological devices. While quality of life has definitely been improved, only a very modest degree of employment potential has been demonstrated. Nevertheless, the client is now ready to continue study of computer science - with special instruction and support.

BACKGROUND

Terry Pierce had completed three years of college with a major in computer science when he became disabled in 1979. During intramural wrestling activity, a blood vessel in the brainstem ruptured rendering him tetraplegic. In addition, his vocal cords and respiratory muscles were severely impaired. Chronology related to his rehabilitation follows:

Date	Event/Status/Location
2/79	Injury, Central State University
2/79- 5/79	Acute care, Oklahoma City, Oklahoma
5/79-12/80	Medical rehabilitation, Oklahoma City
12/80-10/81	Nursing home and part-time at home, remote western Oklahoma.
10/81-12/81	Tulsa Rehabilitation Center, medical rehabilitation and evaluation to determine feasibility of vocational rehabilitation.
12/81- 6/82	Returned to nursing home/at home status. Maintenance only-nothing to enhance employability.
3/82- 4/82	Fund drive at Central State University resulted in collection of about $18,000
6/82- 6/82	Reentered Tulsa Rehabilitation Center for medical reevaluation, to receive special powered wheelchair, Apple II computer and associated assist devices and further evaluation of feasibility of vocational rehabilitation.
6/82- now	Okmulgee Rehabilitation Center, long-term evaluation and effort to determine fastest and best means for communication and computer operation.
2 - 83	Tentatively scheduled to return to nursing home/home situation in remote western Oklahoma.

INTRODUCTION

First Stay At Tulsa Rehabilitation Center

This client was three years post-injury when he first entered the Tulsa Rehabilitation Center. He was considerably overweight (270 pounds and 6'3" tall) and could generate no sound except when he cried or laughed. He could not call the nurse and communicated via an Etran Board.

Figure 1. Terry Pierce, Non-verbal Tetraplegic, Learning To Use MicroDec With Puff-Sip Control.

At the Tulsa Rehabilitation Center, he was immediately provided with a pneumatically controlled nurse call with acoustical feedback which assured him that the call had been initiated. The following day, he was provided with a MicroDec environmental control system which he learned to use in conjunction with his occupational therapists.

Figure 2. Speech Pathologist Teaching Client To Use PROSCAN.

His speech pathologist, who had seen him one year earlier, determined that a PROSCAN (a light pointer, print-out system) would be an appropriate portable communication aid. This proved to be true and greatly enhanced morale and performance of the patient.

The staff was very much surprised when Mr. Pierce could not generate enough positive and negative pressure to actuate the higher pressure pneumatic switches used with the wheelchair. A short throw joystick which he operated with his teeth, was employed with reasonable success. At this time, Terry demonstrated marginal employability potential.

Figure 3. Short Throw Joystick Control Was Operated With Teeth.

Oklahoma Rehabilitative Services purchased a MicroDec system for the client and the IMPART system loaned him a PROSCAN. He returned to a nursing home in remote western Oklahoma. Tulsa Rehabilitation Center recommended that he participate in lessons to learn operation of the Apple II computer but that did not materialize.

Second Stay At Tulsa Rehabilitation Center

A fund drive was held for Terry by his college, Central State University; approximately $18,000 was raised in his behalf. He returned to Tulsa Rehabilitation Center for medical reevaluation, adaptation and training with his new mobility, communication and computer equipment. He received further training in use of the PROSCAN and trouble shooting the MicroDec system, and intensive training in operation of the wheelchair. All components of the computer system had not been delivered when he was discharged.

Extended Stay In Okmulgee Rehabilitation Center

Okmulgee Rehabilitation Center, about forty miles from Tulsa, is operated by Oklahoma Department of Rehabilitative Services. There are no resident physicians on staff but nursing and attendant care services are provided under the supervision of consulting physicians. Additional services provided are speech, occupational and physical therapy. This center is located on the campus of a large technical school and is an ideal site for extended care and housing for severely disabled individuals - particularly those who wish to enter the technical school.

Terry spent about 7 months at Okmulgee Rehabilitation Center. Primary effort was devoted to determination of the most appropriate method for operating the Apple II computer and related equipment.

MATERIALS AND METHODS

Determination of the most appropriate communication method and one compatible with the environmental control and computer operation was the focus of continued technical effort while Terry was at the Okmulgee Rehabilitation Center. The following equipment and control methods were evaluated with the client/patient:

1. MicroDec (with puff-sip control) - For environmental control only.
2. PROSCAN (light pointer) with printer output (unmodified) - Communication only.
3. Northwestern NUCDC System, Nu-Apple Interface NUCDC program - Input to Apple II computer - for communication only.
4. PROSCAN, with output directly into Apple II computer - Communication only.
5. Cypherlog, Morse code input with video display - For communication only.
6. Custom design, puff-sip with Nu-Apple interface and NUCDC program and with special firmware and software - for both communication and environmental control.

RESULTS

Training and practice in operation of these equipments were supervised by the head nurse of Okmulgee Rehabilitation Center. Technical assistance was provided by the rehabilitation engineer of Tulsa Rehabilitation Center and an electronics instructor of Oklahoma State Tech. The effectiveness and Terry's comparative success with each system was as follows:

1. MicroDec - Very successful environmental control; he demonstrated competence in re-programming and trouble shooting the MicroDec equipment.
2. PROSCAN - Successful with the speed of 8 words per minute, best case while in informal communication.
3. Northwestern NUCDC System, Nu-Apple Interface with puff-sip control for Apple II - Fair to good results with a speed of approximately 8 words per minute.
4. PROSCAN with output directly to Apple II computer - Fair to good success with speed of 8 words per minute but with limitations imposed by inability to shift to upper case.
5. Cypherlog (Morse Code) - Very slow. Due to poor breath control, the client was incapable of required rhythm which resulted in speed less than two words per minute, "Canned" and programmable messages and convenient means for 2x magnification of the text are available.
6. Custom design - Training is in progress. This system will undoubtedly prove to be much more convenient because it will not be necessary to switch systems when change from environmental control to communication becomes necessary.

DISCUSSION

Terry Pierce is a client of Oklahoma Rehabilitative Services and his case has been active for a total of 3 years. This agency provided services which include 20 months of medical rehabilitation in private facilities, 8 months in an agency, extended-rehabilitation care facility and his acute care was provided through private insurance. Through fund-raising efforts by fellow students and others, about $18,000 was raised for mobility, communication and environmental control equipment. Much of the rehabilitative engineering services were provided by the Tulsa Rehabilitation Center at no cost.

Figure 4. Client Was Elated With Newly Acquired Abilities.

CONCLUSIONS

The primary system of communication, computer operation and environmental control, will be the basic NUCDC system with additional capability provided by custom firmware and software. The MicroDec system will be used as a back-up for environmental control. The PROSCAN will be used as a back-up for communication.

This client is now ready to resume the study of computer science. However, his home is in a remote section of Oklahoma, and continuation of state supported services is in doubt.

ACKNOWLEDGEMENTS

Mr. Carroll Hostetter, Programs Specialist, Oklahoma Department of Rehabilitative Services, referred this case to the IMPART program in 1981. His request was for methods and devices that would improve employability of the client. The results obtained in improvement of quality of life and employability of this client represents extensive and satisfying collaborative effort by the Oklahoma Department of Rehabilitative Services, Oklahoma State Tech., Tulsa Rehabilitation Center and Mr. and Mrs. L.C. Pierce, the devoted parents of Terry.

The staff of the Tulsa Rehabilitation Center acknowledges our Administrative Director, Mr. Doyal Knowles, who allowed us to provide certain services for which our facility was not compensated.

The technology utilization effort was performed under NIHR Grant #G008003085. Even though the grant has terminated, a modified IMPART program continues in Oklahoma.

Charles J. Laenger, Sr.
Tulsa Rehabilitation Center
1125 S. Trenton
Tulsa, Oklahoma 74120

TECHNICAL AIDS AND ADAPTATIONS MADE BY AN ALTERNATIVE COMMUNITY RESOURCE

C.L. COSTIGAN, O.T.R. AND V.A. LITTLEMAN, O.T.R.
MAPLEWOOD SCHOOL, EDMONDS, WASHINGTON

ABSTRACT

Due to the unique needs of the severely disabled population, often, commercially-made equipment is not available. Therefore, it has been necessary for Occupational or Physical Therapists to design equipment assisting this population to become more independent. Rehabilitation engineers, when available, have been invaluable resources. Unfortunately, rehabilitation engineeers are primarily available through major universities or hospitals.

The purpose of this paper is to present a variety of solutions to rehabilitation engineering problems by using one community resource. Volunteers from a local business contributed their time, expertise, and materials. They made micro-electronic equipment or adapted commercially-available equipment for use with severely involved non-vocal students at Maplewood School, a center for the handicapped.

INTRODUCTION

Maplewood School serves the most severely handicapped children within and surrounding the Edmonds School District, Lynnwood, Washington. Maplewood, like most public schools, does not have access to a rehabilitation engineer nor is it likely that with limited resources, funds would be available for this service. Students receive the services of Occupational, Physical, and Speech therapists and academic specialists. Each child's goal is to develop the necessary skills allowing him or her to function successfully and independently at school, at home, and in the community. For some children to accomplish this goal, electronic and other technical aids may be necessary.

On the market today there are numerous commercially made devices designed to assist handicapped people. For many, these devices require further adaptations once purchased. Because of their severe or unique disabilities, many Maplewood students are unable to use commercial equipment. These students require custom-made interfaces, adaptations, and other technical aids. It is a major problem to find the money and personnel to design and fabricate this equipment.

The ideal situation is for the Occupational Therapist and other team members to work closely with a rehabilitation engineer consultant to develop needed equipment. Rehabilitation engineers, though, have traditionally been associated with universities of found in large urban areas. What options do the handicapped and professionals have, living in communities where these services are not available? One alternative Maplewood School found beneficial was to call on the local telephone company, General Telephone Electronics (GTE). Through contact by the principal and the Community Representative for GTE, a volunteer agreement was established. General Telephone agreed to release employees, and to provide materials and technical assistance. These GTE employees were highly skilled in electrical and mechanical engineering. Although these volunteers had never worked with handicapped persons, the blending of therapists' rehabilitation knowledge and GTE's engineering skill proved extremely beneficial for a number of children. Over a year's time, many hours were spent with child, therapist, and GTE volunteer in designing, evaluating, and redesigning several equipment prototypes before coming up with the present product.

Several challenges were presented to the GTE technical specialists with the subsequent results as indicated:

One:
The redesign of an interface activated by an upward eye movement for a non-vocal child with severe cerebral palsy was needed. The previous experimental eye switch consisted of a photosensor mounted in the right eye piece of a pair of swim goggles. The eye switch had continuous problems with random activation from eye blinks, lack of fine tuning, poor battery connections and battery failures.

Results. A GTE engineer developed a new eye interface, the circuitry of which has been streamlined. The previous switch ran on three separate batteries while the new package uses a transformer and standard house current. The mounting system (goggles) remains the same. The GTE switch now can be fine-tuned to filter out ambient light. In addition, it is more consistent because it is immune to random eye blinks. Activation results when the child maintains direct eye gaze at a red sensor for one (1) second. Even though the performance of the interface switch is more reliable, problems still exist which may be attributed to the child's ability rather than the technical aspects of the switch. This improved interface allowed the staff to better evaluate the child's cognitive and motor function. Additionally, with the eye switch, the child can interface with an Apple II computer to play simple games and perform pre-academic tasks. Due to the child's low cognitive abilities, it appears the primary use of this interface will be for recreational purposes.

Two:
A redesign of a tongue switch interface for a non-vocal child with severe mixed spastic quadriplegia was needed. This child's only voluntary movement is with his tongue. He is unable to keep his head in midline even with the support of a Mulholland wheelchair. His head is either locked in asymmetrical tonic neck reflex spasms to the right,

or left combined with severe extension. When tone is low, head is forward with a severe tremor. With all this extraneous movement, it was difficult to develop head gear that would hold the microswitch securely in place. A tongue-operated, electro-mechanical device held to the child's lower jaw by a plastic chin cup and attached to his head with a hairnet had previously been made. The actual switch portion was a chin cup supporting a micro-switch to which a lever had been attached. This lever extended to an oblong-shaped target positioned approximately 1 cm. from the lower lip. A forward thrust of the tongue forced the level forward, activating a micro-switch.

Results: The GTE volunteer designed a bridle made from metal tubing to fit tightly over the chin and contour of the child's jaw. A new head halter with tension adjustments was made allowing for precise fit and to prevent slippage.

A new solid-state tongue operated device with no moving parts was attached to the metal tubing. The entire device is held stationary approximately 1 cm. from the operator's lower jaw by a metal brace with a halter-type elastic support. This device consists of an insulated metallic target connected by a cable to a type of proximity detector. When the child's tongue touches or comes within 1 or 2 mm. of the target, the device activates and the switch is closed. The sensitivity of the metallic target to touch can be adjusted. This reduces activation by saliva. The electronic portion is located separately from the target and is powered by a standard 9-volt transistor battery.

The child can now activate the switch regardless of head position. This consistent interface switch allows the child to use an Apple II computer as well as being able to try various electronic communication systems. Since this child has normal cognitive functioning but no consistent motor output except for controlled tongue movements, this interface opens up many possibilities for a more independent life (i.e., environmental control systems, improved system of communication.)

Three:
Battery operated toys to evaluate motor function and to teach cause and effect had previously been used with a wafer cable. This proved unsatisfactory because wafer cables continually slipped and could not be used when batteries were not in parallel. The wafer cable was inflexible and frequently interfered with the movement of the toy.

Results. The GTE volunteers installed a jack into all toys allowing flexible cloth-covered cables to be used with more than one toy. With this adaptation, the toys ran more consistently. Evaluation of motor response is now more accurate because the toys are working efficiently.

Four:
Attaching a chin-operated leaf switch to a Mulholland wheelchair for a child with severe spastic quadriplegia was needed. The child could only flex and extend his head activating the leaf switch with this chin movement.

Results. A GTE mechanical engineer designed and produced a quick and efficient mounting system. A ferris metal plate was attached to the child's wheelchair tray to accept a swivel rod with a magnetic base to hold the leaf switch. The child can now operate an electronic toy with his chin without assistance while seated in his wheelchair. This enables the teacher to work on additional communication skills and gives the child some control of his environment.

CONCLUSION

Even though many of these adaptations and development processes appear simple, they were complex and involved a long testing and training process. A series of prototypes were constructed before development of the final product. This continues to be an ongoing process due to the changeability of the child and his needs. The technical knowledge, expertise, time, and materials donated by volunteers from GTE have been an invaluable service to these children and the staff.

Traditionally, community support programs have elicited funds to buy materials for Maplewood. The uniqueness of General Telephone Electronics community support is that in addition to providing funds and materials, their employees (Specialists) have contributed their time, special skills, and worked cooperatively with the Maplewood staff and students to produce highly individualized equipment.

There must be many community businesses with similar sources of creativity and technical expertise in the areas of carpentry, electronics, welding, etc., that could give assistance. It is not just monetary donations, but commitment of services which help professionals to better meet the needs of the handicapped.

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ADDRESS

C. L. Costigan, OTR
Maplewood School
20100 84th Avenue West
Edmonds, Washington 98020

A Resource Center and Database Providing Educational and Vocational Access to Technical Fields for Persons with Disabilities

Helen E. Woodall and Albert M. Cook
Assistive Device Center
California State University, Sacramento
Sacramento, California 95819

ABSTRACT

This paper addresses the need for a reliable retrieval system on adaptive aids. The Assistive Device Database System (ADDS) and associated resource center have been developed to meet this need. The ADDS design and its data content are described and its applicability in the educational, employment and rehabilitation settings are presented.

INTRODUCTION

Students with disabilities are underrepresented in fields of science and engineering. One reason for this is a lack of information regarding methods by which they can both complete educational programs (particularly involving laboratories) and successfully pursue careers. Specifically, information regarding adaptive equipment, altered instructional formats and resources appropriate to aiding students and faculty is not readily available to these people. All too often, college students with disabilities are advised against entering specific fields or taking certain classes for fear their disability will prevent them from full participation.

Much of this situation is the result of 1) lack of knowledge regarding adaptive aids and 2) the failure to procure, develop/modify aids in time for the student to access the class or the employee to meet job requirements. The irony and indeed tragedy of this situation is that an abundance of information on aids exists. Rehabilitation professionals are virtually inundated with information on new products from a variety of sources including conferences, workshops, computer fairs and expositions. With this information explosion, the problem is one of information storage and retrieval.

As a response to these problems, we have developed a resource center, including a computer database that provides information helpful to disabled individuals desiring to study science or engineering.

METHODS

The development of our resource center and database called the Assistive Device Database System (ADDS), was carried out over a two year period. Our approach was to study the manner in which disabled students receive information regarding devices and resources on the 19 campuses of the California State University and College System. Through visits to each campus and meetings with all Directors of Services to Students with Disabilities, we were able to define the informational needs of students, faculty and counselors. This information formed the basis for the development of ADDS. At each stage of development we sought further input from faculty, students and counselors to insure the usability of the system. The final system was designed to be an extension of an already existing counseling system and to easily accessible by the target population.

The format for organization of the information was developed carefully by determining skills required in various laboratory classes, by classifying disabilities functionally and by designing a database that sequentially led the user to more specific information via a series of menus presented on the CRT.

Early in the project, it was concluded that the user should not be required to display knowledge of devices or resources,but should be able to obtain that information via an understanding of two things: 1) the student's disability and capabilities and 2) the tasks required for completion of a given course. It is assumed that this information will be available to the counselor through interaction with the student and faculty member.

Once these two types of information are determined, the counselor, student or faculty member may use ADDS to obtain specific information regarding device resources, bibliographic citations and service providers. In addition, a resource coordinator is available to provide back-up consultation for specific problems not addressed by ADDS. The system has been extensively tested by campus counselors, faculty, vocational, rehabilitation counselors and students. It is currently available to the 19 campuses of the California State University via the central time sharing system.

RESULTS

Four basic types of information are available on ADDS: devices, bibliographic citations, resource persons and service agencies. (See Table 1) The information available on devices is the device name, manufacturer, purpose of the device, its source (vendor), description, the skill(s) necessary for its use and the approximate device cost. Bibliographic information consists of the author, title, source and abstract. The data on resource persons provides the individual's name, address, telephone number, organizational affiliation, speciality and the services offered. Service agency entries contain the agency name, organization, or committee address, telephone number, publication or newsletter (if any) and the types of disabilities served. All information included has been validated by our staff and is continually updated through contact with manufacturers. ADDS contains four general categories of student disabilities: Communication, Manipulation, Mobility and Sensory. A fifth category,interfaces, is available to select ways in which the student will control certain devices. Each of these categories is in turn subdivided. In this way, the user's skills are sequentially defined in a more specific way. Table 2 shows the subdivisions of the Sensory category as they would appear to the user via menus.

DEVICE DISPLAY

NAME	MANUFACTURER	PURPOSE	SOURCE	DESCRIPTION	SKILL	COST	CAMPUS

BIBLIOGRAPHIC DISPLAY

AUTHOR	TITLE	SOURCE	ABSTRACT

RESOURCE PERSONS DISPLAY

NAME	ADDRESS	PHONE	AFFILIATION	SPECIALTY	SERVICES

SERVICE AGENCIES, ORGANIZATIONS, COMMITTEES DISPLAY

NAME	ADDRESS	PHONE	PUBLICATION	DISABILITIES SERVED

Table 1. Display Headings

MENU	DIRECT CODE
:SENSORY:	
1. AUDITORY	
2. VISUAL	
:SENSORY:AUDITORY:	
1. AMPLIFY SOUND.	2,1,1
:SENSORY:VISUAL:	
1. TOTAL VISUAL IMPAIRMENT	
2. PARTIAL VISUAL IMPAIRMENT	
:SENSORY:VISUAL:TOTAL VISUAL IMPAIRMENT:	
1. MEASURE PHYSICAL PARAMETERS	
2. READ INFORMATION	
3. DISTINGUISH COLORS.	2,2,1,3
4. DISTINGUISH CHANGE IN COLORS.	2,2,1,4
5. DISTINGUISH FORMS AND SHAPES	
6. DETECT STATUS OF INDICATOR LIGHT.	2,2,1,6
7. DETECT LINEAR MOTION OF OBJECTS.	2,2,1,7
8. DETERMINE LEVELNESS OF A SURFACE.	2,2,1,8
9. PERFORM TITRATION EXPERIMENTS.	2,2,1,9
10. OPERATE A METRONOME.	2,2,1,10
11. OPERATE A TYPEWRITER.	2,2,1,11
12. DEMONSTRATE WAVE PROPOGATION.	2,2,1,12
13. LOCATE OBJECTS.	2,2,1,13
14. COUNT EVENTS.	2,2,1,14
15. NOTETAKING.	2,2,1,15
:SENSORY:VISUAL:TOTAL VISUAL IMPAIRMENT:MEASURE PHYSICAL PARAMETERS:	
1. MEASURE LENGTH	
2. MEASURE ELECTRICAL PARAMETERS	
3. MEASURE TEMPERATURE.	2,2,1,1,3
4. MEASURE ATMOSPHERE PRESSURE.	2,2,1,1,4
5. MEASURE HUMIDITY.	2,2,1,1,5
6. MEASURE GAS PRESSURE.	2,2,1,1,6
7. MEASURE BLOOD PRESSURE.	2,2,1,1,7
8. MEASURE FLUID VOLUMES	
9. MEASURE ANGLES.	2,2,1,1,9
10. MEASURE ELASPED TIME.	2,2,1,1,10
11. MEASURE WEIGHT OF OBJECTS.	2,2,1,1,11
12. MEASURE BRAKE DRUM WEAR.	2,2,1,1,12
:SENSORY:VISUAL:TOTAL VISUAL IMPAIRMENT:MEASURE PHYSICAL PARAMETERS:MEASURE LENGTH :	
1. RULERS.	2,2,1,1,1,1
2. MICROMETERS.	2,2,1,1,1,2
3. TAPE MEASURES.	2,2,1,1,1,3
4. CALIPERS.	2,2,1,1,1,4

Table 2. Sensory Menu

When one uses the system, an initial set of categories (Communication, Manipulation etc.) first appears followed by the inquiry: In what area does the student (person) need assistance? After the user selects the first category dealing with the most general needs, he/she continues to progress through additional categories each of which is more specific than the previous one. After the user delineates the area in which assistance is needed, the user then selects from four available types of information (devices, bibliographic citations, resource persons, service agencies).

A user can select the device name only, its manufacturer or price. Similar options are available with regard to the bibliographic citations, resource persons and service agency information. The user can therefore elect to view merely portions of the available information or all of it. This ability of the system makes it useful for individuals who are sophisticated with regard to assistive devices as well as individuals who are novices in the area. Hard copy printout of selected devices, citations, resource persons or service providers may be generated after the data are reviewed.

Another related feature of ADDS is its multiple searching capabilities. With ADDS, it is possible to retrieve (for example) all information on devices manufactured by a particular company that cost a specified sum of money (e.g., all writing aids manufactured by Cleo costing less than $75) or it is possible to retrieve all devices of one type manufactured by a particular company (e.g., all reachers manufactured by Abbey Medical.)

This ability of ADDS to control the amount of information retrieved is but one unique feature of its design. The types of data it contains is another feature. In ADDS one can find information not only on commercially available devices but custom made ones as well. Hence, if no commercially available devices are appropriate, it is possible to contact an individual or individuals who have faced similar problems and constructed devices to overcome these problems.

ADDS also contains a category specifying the skills necessary for the device to be used. For example, consider selecting devices in the manipulation category for an individual who requires a writing aid. Unless the available writing aids specify the type of grasp the individual needs to manipulate it,a claw grasp or a pincher grasp, an inappropriate device may be selected. ADDS is also accessible. A person supplied with a password and an account number can directly use the database. This quality is in distinction to similar databases such as ABLEDATA which require intermediaries as information brokers. With this system, the user places a request with a broker who conducts the information search and then relays the information to the requestor. ADDS also contains information regarding which campuses of the CSU system own the device. This allows a potential purchaser to obtain evaluative information relative to the efficacy of the selected device.

Another feature of ADDS' system design is the capability of the users to leave messages with the staff via the database. With this arrangement, a two-way communication between the user and staff regarding new information is available. This information is then examined and placed in an appropriate format for entry into the database.

The latter aspect raises the primary difference between ADDS and other databases, that is, since ADDS is task-driven it can be employed directly by users. Because the system is not arranged according to device names, its usage does not depend upon prior knowledge of devices. Rather, ADDS is organized according to the tasks that an individual needs to accomplish. These tasks then determine which devices are appropriate.

Vocational Applications. The system was originally conceived to aid post-secondary educational access problems, but it also functions quite well in a variety of other situations. The database can provide solutions in the working environment as well. As an example, consider some of the tasks listed under the sensory/visual category: Read Computer Information, Operate a Typewriter, Measure Temperature, Measure Weights of Objects. Employees in addition to students are required to perform these tasks. Also, these tasks are ones that individuals are called upon to perform sometimes at home as well, so the database can be an apropriate source of information regarding daily living aids for rehabilitation counselors.

Current Users of the System. This system has been in operation since Spring 1980 and is available to all 19 campuses of the CSUC system via the state CYBER system. Originally desiged for use by faculty, students and Directors of Services to Students with Disabilities, it has been employed by personnel coordinators, affirmative action coordinators and rehabilitation counselors as well as individuals from private industry. Plans are underway to make the system available to other users such as community colleges and industries both inside and outside of California on a national network.

SUMMARY

ADDS and the associated resource center provide a unique resource to individuals who deserve educational or vocational access to technical fields. Its skill/task format make it usable by individuals who have no knowledge of assistive devices or other resources. The system has been developed with continual input from potential users. Current efforts are directed at making the system available to users outside the California State University System.

ACKNOWLEDGMENT

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Helen E. Woodall
Assistive Device Center
California State University,Sacramento
6000 J Street
Sacramento, Ca. 95819

15.16P

Service Delivery of Special Devices at the Rehabilitation Centre for Children

M. J. Forbes
Rehabilitation Centre for Children

Introduction

Manitoba is a province of slightly over one million people. The Rehabilitation Centre for Children supplies the needs of the handicapped pediatric population of the province with special devices. Special devices generally describes a mobility aid, a seating device, a positioning device outside of a recognized orthosis, and aids to daily living which are not otherwise available. This article describes the system for providing special devices to the client population of Manitoba.

Referral and Assessment Procedures

Patients are initially seen at the Special Devices Clinic. Referrals to the clinic coordinator can be made by a social worker, registered therapist, or any doctor. The clinic team consists of an orthopaedic surgeon, rehabilitation engineer, attending therapists, therapists from the Centre, the parents, sometimes a social worker, and, most importantly, the child. All concerned persons meet for a pre-clinic assessment at which time an evaluation form is completed. The evaluation form helps to highlight possible areas where a special device may be of assistance. At the pre-clinic assessment, all attempts are made to actually try clients in each device being considered. The case is then formally presented to the clinic chief at the clinic. The clinic chief will examine the child and requisition any devices that seem appropriate. Following this the devices are constructed and the patient is called back in a couple of weeks for a final fitting. The final fitting is usually attended by the therapist, parents, and special devices staff. There is no charge to the patient's family for the assessment and clinic service. Any treatment resulting from the Special Devices Clinic is then recorded in the patient's medical record. At present we are holding four to five clinics per month with an average of five to six patients per clinic, one to two of which will be new client referrals.

Half of Manitoba's population is outside the capital city and spread over an area larger than England. This means that many of our patients come from remote areas which presents difficulties in smoothly providing properly fitting devices. What seems to work best is to coordinate well our activities with other agencies and facilities concerned. We will try to accomplish as much as possible on a single visit. Obviously, this means being well prepared beforehand and scheduling the patient's visit to make best use of the time available. The follow-up on out-of-town patients is done by the local nursing station who needs to be kept up to date on the goals and direction of treatment.

Special Devices Structure

The Special Devices Department currently consists of eight people. This includes one half-time technician and one half-time secretary. The others are five full-time special devices technicians, one clinical technician, one rehabilitation engineer (mechanical engineer) who acts as a department head. One technician is permanently located at a 350 bed residential institute for the multiply handicapped. We currently occupy floor space of four thousand square feet. We are equipped to construct anything in metal, wood and plastic. Back-up electronic service is provided by the Biomedical Engineering Department at the Centre. All of the staff were hired with good mechanical aptitude and received their training on the job. None have been hired with previous experience in the rehabilitation engineering fields

Statistics

Three tables are included which show the distribution of special devices for 1982.

Table I Distribution According to Function

Seating	183
Standing	47
Mobility	83
Aids to Daily Living	130
Communication Devices	7
* Recreation	18

* mostly adaptations to bikes or trikes

Table II Distribution According to Diagnosis

* Cerebral Palsy	168
Seizure Disorder	47
Developmental Delay	19
Muscular Dystrophy	26
Spina Bifida	22
Mental Retardation	26
Post Motor Vehicle Accident	10
Other	44

* includes Spastic Quadriplegia, Hemiplegia Microencephaly with Spasticity

Table III Patient Distribution

Female	177
Male	183
Total	360
In Patient	79
Out Patient	281
Total	360

Funding

The mandate of special devices is to provide technical aids of primarily a mechanical nature and which are not available either commercially or through other programs. We service the pediatric population (i.e., 18 years and under) of Manitoba. This service is funded annually by the provincial government Department of Health. The funds are given back as a block budget and not a fee for service. Table IV gives some financial indicators which may be of value to the reader.

Table IV Financial Indicators

Dept. Cost per Dept. Hour	$ 14.91
Dept. Cost per Patient Visit	$407.05
Dept. Average Hourly Salary	$ 10.34

Since all devices are continually being refined and developed this is carried on as part of the regular service program. More expensive development of new devices must be amortized over several clients from a waiting list or covered by a research grant. All scientific research must be covered by a grant from an outside agency.

As far as devices that are already commercially available, we are only responsible for modifying them. For example, parents must supply a stroller into which we put an insert. We only modify walkers that are available through rehabilitation supply catalogues. The parents must either pay for these themselves or go through a sponsoring agency.

Because we have developed devices and pieces of hardware which are extremely useful to others besides ourselves, we have generated sales to out of province centres. Although this is not a lot, it does mean extra income and gives us some flexibility in budgeting. Caution is advised not to overburden the service program with manufacturing for out of province. Our solution is to subcontract as much of the manufacturing as is possible and reasonable. The biggest reason for our sales program is to help other smaller centres who are faced with problems to which we have found a solution.

Summary

The system described here for the provision of aids to residents of Manitoba is an equitable and workable program. There are still weaknesses in the provision of more complicated (especially mechanical-electronic devices) economically and within a reasonable delivery time to a large number of patients. Also, a device of a rehabilitative nature but commercially available must be paid for elsewhere which puts the burden on the parents in some cases. However, this system is strong on providing simple and up-to-date devices economically to many clients.

633 Wellington Crescent
Winnipeg, Manitoba, Canada R3M 0A8

AMPUTATION LEVEL DETERMINATION
IN PATIENTS WITH PERIPHERAL VASCULAR DISEASE

GOLBRANSON, Frank L., M.D., WIRTA, Roy W., BSME, and FRONEK, Arnost, M.D.
Veterans Administration Medical Center and University of California,
San Diego, California

ABSTRACT

Although several investigators in the United States have reported high percentages (more than 90%) success rates in stump healing in patients with peripheral vascular disease, the fact that these success rates have generally not been achieved in the nation at large indicates the need for additional methods to determine with reasonable reliability amputation levels that will heal in patients with vascular insufficiency.

At Veterans Administration Medical Center and University Hospital, San Diego, amputation level determinations have been made on the basis of (1) physical findings such as arterial pulses, level of skin demarcation, and observation of skin capillary fill rate, (2) skin bleeding at the selected level of amputation, and (3) non-invasive techniques. These techniques are (a) segmental pressure readings since 1972, (b) skin temperature measurement using a thermistor since 1978, and (c) transcutaneous oxymetry since 1979.

SEGMENTAL PRESSURE EVALUATION

Although we believe that segmental pressure evaluation reveals valuable information about the status of the major arterial pathways, this data has not been a totally reliable method of determining extremity hemodynamics. This may be related to two circumstances:

(a) The standard sphygmomanometric pressure measurement reflects primarily the arterial pressure in the skeletal muscles.

(b) The so called "blood pressure or ischemic index" (arrived at by dividing the arm pressure into the given segmental pressure) has not always been a reliable skin healing indicator since in 15% of our patients medial arterial wall sclerosis causes spurious elevated distal pressure values. Therefore, we use segmental pressure values primarily to supplement $TcPO_2$, and thermistor results.

THERMISTOR

In 1978 we noted that a thermistor had been used to record skin temperatures in distal areas of replanted upper extremities. Previously, other investigators had correlated skin temperature and cutaneous blood flow, and we therefore selected the thermistor to evaluate skin blood flow in our patients with peripheral vascular disease.

Skin temperature studies were done in hospital patient rooms where ambient temperatures were recorded. We used a telethermometer Vpi series 400, model 46 TVC made by Yellow Springs Instrument Company. Skin temperatures were recorded over the anterior aspect of the lower extremity at 2 inch intervals starting at the toes and extending just proximal to the patella when the lesions were distal.

RESULTS

In a prospective double bind study, 31 amputations were done in 27 patients, 18 of whom were diabetics. 26 or 82.8% healed and 5 or 16.2% failed. All healed stumps had pre-operative skin temperature readings above 32° C. All stumps with readins below 30.5° C failed.

When examining the difference between room temperature and skin temperature, we found that in all healed patients the difference between room and skin temperatures was more than 5° C. In our unhealed patients the difference was less than 5° C.

We plan to continue this study and, at present, we think that it will be a valuable method for assessment of extremity skin blood supply in patients with peripheral vascular disease.

$TcPO_2$

Based on the premise that skin healing is directly related to available O_2 we began $TcPO_2$ measurements in 1979.

Measurement of transcutaneous O_2 tension ($TcPO_2$), using a modified Clark-type oxygen electrode, has become a well established method in neonatal medicine.

About 100 years ago, diffusion of oxygen molecules through the skin was demonstrated. It was found that reactive hyperemia induced by local heat improved the accuracy of the $TcPO_2$ measurement. The Hellige (Litton) system used in our study uses a probe consisting of (1) three platinum cathodes and a silver anode, (2) a heating element, and (3) a thermistor to control preset temps.

$TcPO_2$ Continued

We measured the $TcPO_2$ in the subclavicular region which we used as a reference point or control. $TcPO_2$ was also measured in the lower extremity in two areas - one, the dorsum of the foot and the other, the anterior leg 10 cm distal to the knee joint line. In recent months we have included monitoring after 10 minutes of 100% breathing.

In 35 patients we evaluated the resting $TcPO_2$ and noted healing in 32 patients with readings of above 5 mm Hg. Three patients healed with readings below 5 mm Hg. In 25 patients, where resting $TcPO_2$ and 0_2 breathing techniques revealed $tcPO_2$ tension of more than 5 mm Hg, all patients healed.

The conclusion from our current experience is that changes for per primum healing are very poor if:

(a) $TcPO_2$ values at rest is 5 mm Hg or less.

(b) There is no increase in $TcPO_2$ level at the end of the 10 minute exposure to 100% 0_2.

SUMMARY

In determining successful lower extremity amputation levels in patients with peripheral vascular disease, we have attempted to add more objective methods by the use of the described techniques. Our favorable results of 83.8% healed in the thermistor study and 91.4% and 100% in the two $TcPO_2$ studies encourage us to continue their use.

Although we have found the above methods helpful, none of these supplant a careful history and physical examination including lower extremity pulse evaluations.

Frank L. Golbranson, M.D.
Chief, Rehabilitation Medicine Service
Veterans Administration Medical Center
San Diego, California 92161
Clinical Professor of Surgery
University of California, San Diego
San Diego, California 92137

THE EARLY DETERMINATION OF LIMB VIABILITY

Brotman, S., Meyers, R.A.

The determination of limb viability following crushing injury remains one of the major problems facing trauma surgeons today. Resurgance of interest in external fixation coupled with advanced in anti-biotic and hyperbaric therapy has encouraged many trauma surgeons to try to retain unsalvagable limbs at great risk to the patient. A retained non-viable extremity may elaborate myotoxins leading to sepsis, renal failure and death.

Faced with problems of early determination of limb viability in major injury of the extremity, the Maryland Institute for Emergency Medical Services Systems began a systematic study of limb viability. The standard for comparison has always been the surgeon making daily wound rounds, debriding and operating when necessary. Laboratory evaluation primarily centered about the renal function testing has also been quite reliable. Unfortunately neither method gives particularly early warning. More sensitive experimental studies of the circulation with fluorescein, xenon or thallium seemed to be indicated.

MATERIALS AND METHODS

Fluorescein - 12 patients with crushed extremities were studied by injection of 2cc fluorescein intravenously and then observed under a Woods Lamp. Although the skin fluoresced, fluorescence of the muscle was poor. In almost all cases of severe crush, the injury was much greater than predicted by fluorescence of overlying skin.

Xenon^{133} - Inhalation Technique. 8 patients with injured extremities were studied by having them inhale Xenon^{133} gas. The method was non-invasive and allowed the physician to study both extremities simultaneously. Xenon travelling primarily in the blood stream seemed to indicate the degree of functional vasculature. However, 25% of patients in this series despite "normal" studies required amputation.

Thallium Scan. Thallium is a potassium analogue actively transported intracellularly by the Na/K pump, it is taken up by viable cells. Uptake is dependent on tissue oxygen levels, and blood flow. The one advantage of the thallium scan is that one can use two different limbs for comparison.

The major problem experienced in attempting to use the thallium uptake as an indicator for oxygen treatment, is the ordering of thallium requires a 24 hour delay. To date 10 patients have been studied. Results are being analyzed.

The transcutaneous oximetar has been used in a few cases indicating that when tissue O_2 levels are below 40mm torr of oxygen, the circulation through the skin capillaries is reduced. This however may reflect vascoconstriction or cold weather and not the underlying problems. Equally important is the fact that in certain circumstances, the capillary flow through the skin may be uneffected and yet the underlying muscle is crushed and non-viable.

The crush syndrome is not a static process. It may be progressive as it may in some instances be reversed. Marginal tissue with borderline oxygen supply may be salvaged by the addition of high oxygen concentration in the blood under hyperbaric oxygenation, which raises the arterial O_2 level to nearly 2,000 mm oxygen torr. This exceptionally high level of oxygen, particularly in the plasma, enables the tissue in the area of a crushed limb to be saturated with oxygen, thus possibily allowing some marginal tissue to be salvaged. In addition to this action, high oxygen concentrations raise the tissue oxygen levels at the site of injury to the minimum required for fibroblast and osteoblast proliferation which is in the range of 30 - 40 mmHg O_2 torr. 6 patients with crushed limbs were treated with 2 - 3 dives a day for the first 3 days; thereafter, a single daily dive was given. The results have been encouraging, but additional cases for study are required.

DISCUSSION/CONCLUSIONS

The evaluation of the crushed extremity remains a significant problem. Basic studies to evaluate the blood flow using angiography, fluorescein and xenon_{133} are not sensitive enough to show function at a cellular level. Thallium may show some promise but additional studies are required. The best evaluator in 1983 remains the surgeon who will religiously each day inspect the wound. A need for more research in this field is obvious.

Maryland Institute for Emergency Medical Services Systems, 22 South Greene Street, Baltimore, Maryland 21201

LIMB VIABILITY STUDIES

Ernest M. Burgess, M.D.

Director, Prosthetic Research Study Center

ABSTRACT

Selection of the level of amputation continues to be one of the most important determinates in amputee rehabilitation. This is particularly true when a major joint is involved, i.e., knee and elbow. The great majority of the limb threatening peripheral vascular disease involves the lower limb. Needless sacrifice of length to insure primary wound healing can make the difference between wheelchair mobility or successful walking with a prosthesis. One of the great advances in amputee surgery during the last decade has been the successful lowering of amputation levels by better understanding of limb viability and by improved surgical and immediate postsurgical techniques.

The experienced amputation surgeon can successfully operate at lower levels consistently. Unfortunately, this quality of surgical judgement is not generally present with many surgeons who perform amputations. Not only does the experienced surgeon need objective data to determine the proper level of amputation, the surgeon who performs an amputation only occasionally can to an even greater degree benefit by noninvasive, measurable evaluation of limb viability and healing potential.

This paper reviews both clinically accepted measurement of limb viability and those studies now under experimental investigation. Emphasis on transcutaneous gas perfusion, blood pressure and small artery dynamic blood flow, radioisotope washout, fluorescene staining and other related techniques are identified. Ischemic limb screening for perfusion is described. The nature of skin healing in the presence of ischemia is presented on the basis of biological structure. Standardized microwounds earlier placed and subsequently harvested from amputated limbs in patients with peripheral vascular disease provide the experimental model.

The presentation concludes with formulae for practical use of the newer technology. Clinical application and prospective research are considered.

GAIT ANALYSIS AND ALIGNMENT SYSTEM FOR LOWER-LIMB PROSTHESES

Maurice LeBlanc, MSME, CP and Wallace Sumida, BSEE, CP
Children's Hospital at Stanford, Rehabilitation Engineering Center
Palo Alto, California (1)

ABSTRACT

At present, dynamic alignment of a lower-limb prosthesis is done by the prosthetist using a visual, trial-and-error technique with feedback from the amputee. It is a time-consuming process and the final alignment is not reproducable. This paper puts forth the concept of a system whereby the amputee can align his/her own prosthesis based on comfort and lowest energy expenditure, and the final alignment can be recorded and reproduced. The goal is a clinically optimum and measurable adjustment of lower-limb prosthesis for improved ambulation.

INTRODUCTION

There are an estimated 210,000 lower-limb amputees in the USA (2). Comparison with other countries such as England and Sweden show a similar incidence per population. There are about 1400 certified prosthetists serving this amputee population in the USA (3).

When a lower-limb prosthesis is made, it is first statically aligned at the bench and then dynamically aligned or "tuned" to the amputee's gait. The dynamic alignment is done by visual observation of the prosthetist according to guidelines established by analyzing normal gait.

BACKGROUND

There are several problems inherent in the present method of dynamic alignment of lower-limb prostheses:

*The quality of the alignment depends upon the quality of the prosthetist to visually arrive at the optimum gait.

*It is a time-consuming, trial-and-error process to have the amputee stop, make adjustments manually, and walk again to visually assess changes in gait until the optimum is achieved.

*The present method of alignment is not measurable or repeatable. Once optimum is achieved, the alignment is duplicated in the final prosthesis by a transfer or "duplication" jig. No alignment measurements are recorded, so each new prosthesis must go through all the same steps.

*The present method produces no hard data to use for assessment or research to bring more objective data or "science" to a process which is largely "art" dependent on each prosthetist.

The guidelines for optimal alignment which the prosthetist uses were set forth by Radcliff (4,5) and established by analyzing normal gait. However, it is possible that optimum gait for an amputee will be determined more by comfort and least energy expenditure than normalcy of gait. It is well known that amputees frequently have a "clinical gait" when under observation and a "community gait" when unobserved.

The alignment units now being used are mechanical systems in practice for nearly 25 years. The adjustments are relatively gross and offer no means for accurate readout of settings. New types of modular and endoskeletal prostheses have been developed and made commercially available in recent years, but the dynamic alignment remains "old school".

PREVIOUS WORK

Hobson, Foort and Nelson built and tested a powered alignment unit which controlled positions of the foot on lower-limb prostheses (6). With trials on 12 subjects, results indicated that below-knee amputees were capable of aligning their prostheses and, in fact, were more consistent in doing so than prosthetists. However, above-knee amputees found it more difficult to sense changes in alignment and arrive at optimum adjustments. The powered alignment used was tethered by cable to the amputee and the prosthetist for operation. While this study was not continued, it was very important in demonstrating the concept of self-alignment by amputees.

Wilson initiated studies to identify the relationship between alignment and locomotion performance of above-knee amputees with prostheses (7). He and Wirta designed and built an alignment unit to pursue this work, which has not yet been resumed.

Berme, et. al. designed and built a simple device to determine the longitudinal axis of prosthetic sockets to enable the alignment between the socket and the rest of the prosthesis to be measured and recorded (8). The focus of this work was determining the axis of non-geometrical sockets and then relating that axis to the pylon and floor.

Stallard et. al. (9) reported on their work of the development and use of a heart rate telemetry system for clinical decision making in monitoring ambulation. They found heart rate to be an indicator of energy expenditure and a good tool in assessing treatment and clinical procedures.

CONCEPT

The idea is to develop and test a gait analysis and alignment system which can be used clinically for optimum and measurable adjustment of lower-limb prostheses for improved ambulation. The following hypotheses are proposed: (See Figure 1)

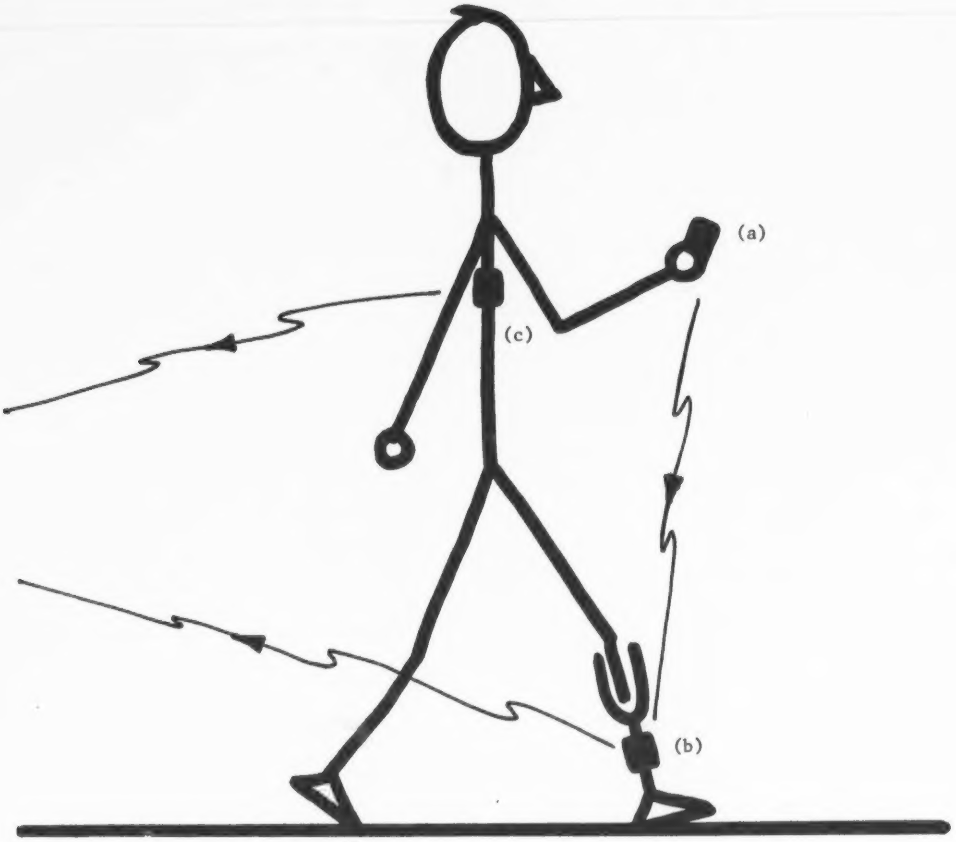

Figure 1. Gait Analysis and Alignment System

(a) Hand-held or belt-held telemetry transmitter which controls the alignment unit. To be used by amputee as shown or by prosthetist.

(b) Gait analysis and alignment unit with information being sent to remote receiver and then processed and recorded.

(c) Heart rate telemetry unit with information being sent to remote receiver and then processed and recorded.

*Assuming an adequate fit and comfort of socket, lowest energy expenditure is the best indicator/measurement of alignment and functional gait.

*The amputee will do a better job of aligning a lower-limb prosthesis by feel that a prosthetist will do by using rules.

*The optimum alignment of a lower-limb prosthesis will more nearly approach that of the limb on the sound side than that of standard guidelines for normal gait.

DISCUSSION

The goal of this proposed project is to improve the gait of lower-limb amputees by the concept put forth above. The three hypotheses would be tested by designing and building an alignment unit and testing it with amputees and prosthetists.

The variable of socket fit and resultant comfort would be minimized in the study by conducting the trials of the analysis and alignment unit twice, once each time with different sockets made by different but capable certified prosthetists. Trials would be conducted with below-knee amputees initially and then with above-knee amputees if the work merits continuation.

A commercially available heart rate telemetry system would be used to monitor energy expenditure.

The potential impact of the project initially would be on prosthetists. The importance and benefit of such a project would have to be demonstrated to and accepted by these professionals if it is to have any impact. Once accepted, it could readily be made commercially available by manufacturers and eventually reach the amputee population through clinical use by prosthetists.

It is an intriguing idea to have amputees dynamically align their own lower-limb prostheses. The work of Hobson et. al. previously mentioned confirms the potential for it to be successful. With technology available now, the time is ripe to test the concept.

ACKNOWLEDGEMENTS

The idea was originally presented in-house by co-author W. Sumida. As put forth in this paper, the project has been proposed for funding by the National Institute for Handicapped Research as part of a larger research effort.

The authors have also been in contact with A. Bennett Wilson Jr., one of the pioneers of modern prosthetics. Coincidentally, he has proposed a similar idea using a mechanical alignment unit with above-knee amputees and submitted a proposal to the Veterans Administration Rehabilitation Engineering Research and Development Service for research support.

REFERENCES

1. Children's Hospital at Stanford, Rehabilitation Engineering Center, 520 Willow Road, Palo Alto, CA 94304, (415) 327-4800, x 348.

2. LeBlanc, M. A., "Patient Population and Other Estimates of Prosthetics and Orthotics in the USA", Orthotics and Prosthetics, September 1973.

3. McCulloch, W.L., American Board for Certification in Orthotics and Prosthetics, Alexandria, VA, personal communication, October 5, 1982.

4. Radcliffe, C. W., "Functional Considerations in the Fitting of Above-Knee Prostheses", Artificial Limbs, National Academy of Sciences, National Research Council, Washington, D. C., Vol. 2, No. 1, January 1955.

5. Radcliffe, C. W. and Foort, J. "The Patellar-Tendon-Bearing Below-Knee Prosthesis", Biomechanics Laboratory, University of California, Berkeley and San Francisco, USA, 1961.

6. Hobson, D. A., "A Powered Aid for Aligning the Lower-Limb Modular Prosthesis," Bulletin of Prosthetic Research, BPR 10-18, Fall 1972.

7. Wilson, A.B., Jr., "Studies Involving Alignment of Above-Knee Prostheses", Bulletin of Prosthetics Research, BPR 10-32, Fall 1979.

8. Berme, N., et al, "Measurement of Prosthetic Alignment", Journal of Prosthetics and Orthotics International, Vol. 2, No. 2, August 1978.

9. Stallard, J., Rose, G. K., "Clinical Decision Making with the Aid of Ambulatory Monitoring of HeartRate", Journal of Prosthetics and Orthotics International, Vol. 4, No. 2, August 1980.

THE ROLE OF IONOMER RESINS IN DEFINITIVE PROSTHETIC APPLICATION

Bruce P. McClellan, C.P.O.
Susan Kapp, C.P.
The University of Texas Health Science Center at Dallas
Prosthetics - Orthotics Program

INTRODUCTION

For the past three decades thermosetting plastics have been utilized in the fabrication of sockets for artificial limbs. The polyester resins have played the most significant role in this area, especially with regard to definitive prosthetic fittings. Over this period of time the thermosetting plastics have proven to be effective for this application and their use continues today as the accepted state of the art. As with any material, however, the polyester resins have certain characteristics which are not ideally suited for all situations. With this as a basis, the University of Texas Health Science Center at Dallas, in conjunction with the Dallas Rehabilitation Institute, began investigating the use of alternative materials for definitive prosthetic design. One of the most attractive substitutes appeared to be thermoplastics. A clinical study was undertaken to evaluate the group of thermoplastics known as ionomer resins and their role in definitive prosthetic application, as opposed to the polyester resins currently in use today.

THERMOSETTING RESINS

The introduction of thermosetting plastics to the prosthetic profession in the early 1950's began what truly can be described as a revolution (1). Prior to this, wood, metal and leather were the materials of choice for the fabrication of prostheses largely because of their ability to be shaped and contoured. Polyester resins impregnated into a cloth medium offered the advantages of a more intimate socket fit, increased residual limb weight bearing, reduced bulk and weight, and improved hygiene.

The most commonly used polyester resin in the prosthetic profession is 4110 laminac. This is a mixture of rigid and flexible resins which may vary from a proportion of 90%-10% to 80%-20% with the rigid resin representing the greater amount. Additional flexible resin may be added to the 4110 mixture to increase flexibility but special curing may then be required if the amount exceeds 25%.

The procedure of fabricating over a modified positive cast of the residual limb with polyester resin became known as "laminating" because of the layers of felt and nylon employed in the process. This laminating process can be time consuming and involves the use of toxic catalyst and promoting agents to induce the required setting reaction. Noxious fumes are also precipitated as a by-product of this procedure. Once cured, however, the plastic is relatively non-toxic and can be used in direct contact with the skin except in rare cases where individuals may exhibit a contact dermatitis reaction. These sockets are not easily modified except by grinding and are fairly rigid in nature. It is this laminated structure, however, that contributes to the strength and durability of the polyester resin sockets.

IONOMER RESINS

The thermoplastics which were utilized in this particular study of prosthetic application are classified as ionomer resins. These resins are based on copolymers of ethylene and methacrylic acid which are partially reacted with metallic salts to form ionic crosslinks between acid groups of a single chain or between neighboring chains (2). The name "surlyn" is the registered trademark of the ionomer resins produced by Du Pont and was the material used in the fabrication of the prosthetic sockets. Some of the characteristics which made surlyn an attractive option for prosthetic use are as follows:

Clarity
Surlyn is virtually transparent even in thicknesses up to 1/4 inch. This allows the prosthetist to evaluate socket fit visually while the patient is standing with full weight bearing on the residual limb (Fig. 1).

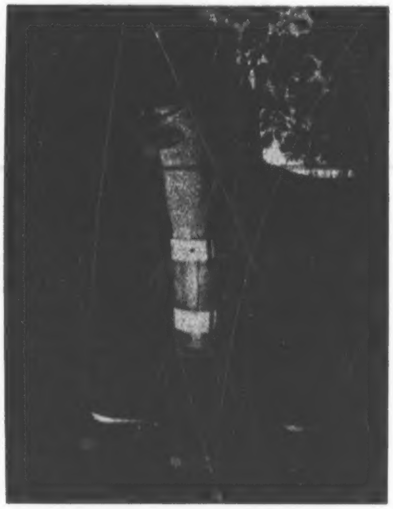

Fig. 1.Symes amputee with clear surlyn prosthesis.

Adjustability
The nature of ionomer resins is compatable with heat induced molding which greatly facilitates modifications to the socket. Areas of pressure over bony anatomical structures are simply heated and relieved with no adverse affect on integrity or clarity of the material. Surlyn may also be buffed, sanded, drilled and riveted in the same manner as the laminates.

Ease of Fabrication

Surlyn comes in a sheet form and is heated and softened in an oven to allow drape vacuum forming. Unlike other thermoplastics, surlyn can be formed directly over a wet cast with no need for a lacquer coating or nylon stocking innerface. This differs greatly from polycarbonates which require pre-fabrication dehydration and a dry cast for good results. Additionally, no post-fabrication curing is required to drive off skin irritating styrene gas, as in the case of polyester resin with a greater than 25% flexible resin content. Additional fabrication time is required, however, in the case of long below knee and symes level amputations because of the need to weld the posterior seam of the surlyn socket.

Flexibility

This factor has proven to be the most significant advantage of ionomer resins from the patients' standpoint. Sockets fabricated from surlyn have much greater flexibility than those fabricated from polyester resin. Patients report that the socket feels more like a part of them and is appreciably more comfortable. The exact deformation occuring in the socket during ambulation has not been quantitatively measured at this point, but clinical trials indicate that anatomical weight bearing surfaces are not adversely affected by the dimensional changes.

CLINICAL APPLICATIONS

Initially, the ionomer resin sockets were used only as "check" sockets prior to fabrication of an intermediate or definitive prosthesis. Later, use broadened to include intermediate prostheses and eventually definitive application. The move toward definitive use was prompted by the patients themselves. Those who had been wearing intermediate prostheses made of surlyn complained of the rigidity of the laminated socket when their permanent prosthesis was delivered. Of the ten patients who were definitively fitted with surlyn, eight of them were symes level amputees. The remaining two patients were below knee amputees (Fig. 2).

CLINICAL RESULTS

The fittings of the ionomer resin sockets for definitive use began in April of 1982, with the last fitting in this group being done in November of 1982. In the symes amputee group, five of the eight patients experienced failure of the prosthesis at the ankle/foot juncture (Fig. 3). The shortest use time until breakage being 14 days and the longest being 5 months, with a mean of 11 weeks for the group experiencing breakage. Two of these patients were refitted with a second surlyn definitive, one of which failed again at 2 months, while the other prosthesis continues to function 6 months after a modified ankle/foot juncture was devised (Fig. 4). The modification made was one of reinforcing the distal end of the socket with glass cloth adhered with acrylic resin. This same method has since been used on two other prostheses in the symes group with those patients continuing to ambulate without incident after six months. The remaining patient in this group was an elderly lady who is a limited household ambulator and has experienced no problems after eight months.

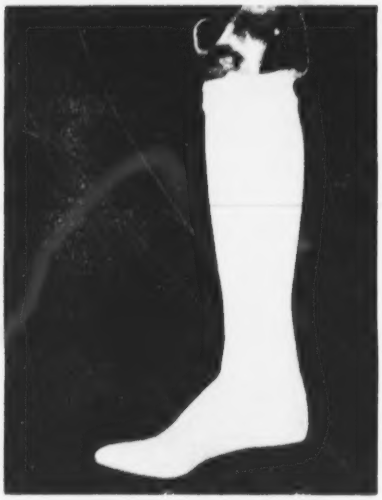

Fig. 2. Below knee type prosthesis with ionomer resin socket.

The two below knee amputees have been wearing their prostheses for 5 and 11 months respectively. The patient with 11 months of experience is an active man who weighs in excess of 230 pounds and participates in sports on a regular routine basis. He recently developed a crack in the proximal posterior edge of the socket and currently the cause of the crack is being examined. The other amputee is a 110 pound woman who has experienced no problems to this point in time.

Fig. 3. Stress fracture at ankle/foot juncture of Symes prosthesis.

Fig. 4. Closed socket design type now being used with reinforced ankle.

CONCLUSION

As indicated by Stills and Wilson (3), surlvn may not be ideal for applications where high unit stresses are anticipated. Although this seems to have been borne out in this initial group of patients, we still believe that ionomer resins might play an important role in definitive prosthetic fittings. This may be accomplished by reinforcement at crucial stress points; a variation in the ionomer resin itself; or by finding a different material that is better suited to long term stresses.

The potential benefits of ionomer type resins to the amputee population are too great to dismiss without further evaluation and clinical analysis. It is hoped that others in rehabilitation related professions will actively participate in seeking viable materials for definitive socket application.

REFERENCES

1. Aylesworth, R. Deane, ed., Manual of Upper Extremity Prosthetics, Artificial Limbs Project, University of California, Los Angeles, 1952.

2. Du Pont, E. I. De Nemours and Company (Inc.), Surlyn Ionomer Resins Industrial Extrusions Manual, pp. 3.

3. Stills, Melvin, and A. Bennett Wilson, Jr., A New Material in Orthotics and Prosthetics, Vol. 34, No. 3, pp. 29-37, September 1980.

Bruce P. McClellan, C. P. O.
Assistant Professor and Director
Prosthetics - Orthotics Program
University of Texas Health Science Center at Dallas
5323 Harry Hines Boulevard
Dallas, Texas 75235

CONTROL INTERFACE STRATEGIES

D. S. Childress

Northwestern University Rehabilitation Engineering Program

INTRODUCTION

Our hands and arms play an enormous trick on us. Their skillful and dextrous movements, carried out so effortlessly and with such grace, make us sometimes believe we should be able to construct artificial replacements that operate in a similar fashion. But when we consider the matter more carefully we realize the folly of this notion. We may even wonder if we have taken the first step on the journey to limb replacement by technical devices. Nevertheless, there are certain strategies that may help our thinking in the complex task of artificial limb design, construction, and prescription. Strategies I believe important are as follows:

No Limb At All

The rejection of an artificial limb should be one of the options that are, without criticism, open to an amputee. Technical people associated with amputee rehabilitation should be supportive of this kind of decision, if it is not detrimental to the person's health. The benefits of no prosthesis are physical comfort, unencumbered sensory input, and (sometimes) better function.

Cosmetic Prostheses

Modern materials make cosmetic restoration possible with great authenticity. For a certain percentage of amputees, the restoration of appearance is the most important aspect of prosthetics. A cosmetic prosthesis can often achieve the intended result in a light-weight form and at moderate cost. A cosmetic prosthesis may also complement a more functional limb through occasional use for dances, the theater, church, and social events of many kinds. Lack of color stability, poor stain resistance, and poor durability of prosthetic skin are main problems associated with cosmetic limbs.

Passive Prostheses

Passive prostheses may also be very cosmetic and light in weight. Components are termed passive if they have no active parts. They often require the assistance of the contralateral limb for function. For example, a passive hand, held closed by a spring, needs to be opened by the opposite hand if it is to hold an object between its fingers. A passive elbow may need to be moved to its desired position and locked by the person's physiological limb. Passive components are incorporated into almost all prostheses.

Cable-Driven Prostheses

Although the Bowden Cable was invented about 1885 it was not used extensively in prosthetics in America until about 1950. Prostheses that use this strategy are used more frequently than any other artificial limb. These prostheses are functional, lightweight, comparatively simple, and their direct coupling to a body movement integrates them well with the human operator. If we had invented them in 1980, we would perhaps think more highly of these prosthetic workhorses.

Powered Prostheses

Powered prostheses (i.e., not powered by the body) have been under development since World War I. Nevertheless, extensive work in this area did not begin until after World War II and much of the work has occurred over the last 20 years. Powered prostheses offer the possibility of a functional arm to amputees who cannot use body-powered prostheses. They also can give a nice cosmetic effect (dynamic as well as static) while being functional. They can give strong outputs even with low-level inputs. They have the potential to relieve the amputee of control harness.

Powered prostheses are only used by perhaps ten percent of upper-limb amputees in America. These prostheses have much potential. They need to be made more reliable and more easily handled in the field.

(a) Velocity Control

Most powered prostheses are velocity controlled, either by on-off (switches) or proportional transducers, when the actuator is not stalled. Myoelectric signals are frequently used to give on-off or proportional control of velocity. While velocity control serves well for the control of one function it generally is less applicable for multi-functional control in its more simple form. Velocity control tends to create phase lag and overshoot when used in tracking tasks if the powered actuator moves the joint at rates above about two radians/sec.

(b) Position Control

Very few powered prostheses use position control. Nevertheless, this is the kind of control which serves so well in body-powered prostheses. Dr. David Simpson in Edinburgh has shown this approach to have much value. It remains a largely unexploited control strategy for limb prostheses.

Hybrid Prostheses

A hybrid prosthesis is any that uses more than one kind of component in it. In practice, the term is usually reserved for prostheses that are electric powered and body powered. Hybrid prostheses have much potential for the bilateral, high-level amputee. For example, Mr. John Billock has fitted bilateral above-elbow amputees with myoelectrically controlled hands (biceps-triceps) body-powered elbows (shoulder protraction) and forearm rotations (switch-controlled by shoulder elevations). These prostheses also have passive forearm flexion.

CONCLUSION

The fitting of prostheses to amputees is a complex process in which the control strategies and hardware may play less of a role than engineers would like. Psychological and sociological issues as well as client-provider interaction may have more overall importance to amputees than the control strategies or the mechanisms. However, if these issues are handled well, then it is possible for the more technical side of limb prosthetics to influence the degree of achievement possible by persons with limb deficiencies.

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ADDRESS

Northwestern University
Prosthetics Research Laboratory
345 East Superior, Rm. 1441
Chicago, Illinois 60611

PVA STUDENT DESIGN COMPETITION

Forty-two entries were submitted for judging, of which six papers were chosen as winners, consisting of three undergraduate students and three graduate students. We welcomed the participation of new students and schools and hope that this trend continues in the future.

Special recognition is expressed to the following judges of the PVA Student Design Competition:

John Brabyn, PhD, Smith-Kettlewell Institute of Visual Sciences, San Francisco, CA;

Dave Jaffe, Palo Alto VA Medical Center, Rehab R&D, Palo Alto, CA;

Ken Morgan, Corning Glass Works, Corning, NY;

Barry Rodgers, Trace Center, University of Wisconsin, Madison, WI;

Woody Seamone, Johns Hopkins University, Laurel, MD;

John Trimble, PhD, Hines VA Medical Center, Rehab R&D, Hines, IL.

This year's prize money was provided by the Paralyzed Veterans of America and New Frontiers, Inc.

Gary W. Kelly
Theresa M. Ackerman
Co-Chairpersons
PVA Student Design Competition

ADJUSTABLE DESK

Terry Brownridge, Gilbert Battistin, Allan Fraser
McGill University, Montreal, Canada

ABSTRACT

In Montreal's MacKay Center for Deaf and Crippled Children and other similar educational institutions, there is currently a need for mobile desks that are adjustable in height and tilt for students that are confined to wheelchairs. A full-scale prototype has been designed, built and tested.

BACKGROUND INFORMATION

At the MacKay Center there is a program which involves assimilating handicapped students into a regular school environment. This program is extremely beneficial to the handicapped students, as in being placed in regular schools they are able to learn how to function more efficiently in society.

One of the problems in carrying out this program is that for most of these handicapped students regular school desks are not suitable. The students require a special desk that can be transported from class to class with them. Also many handicapped children do not have the necessary motor skills to write properly and, therefore, take notes with the help of an electric typewriter. Bad eyesight and very severe disabilities necessitate the tilting of the desk surface for some students.

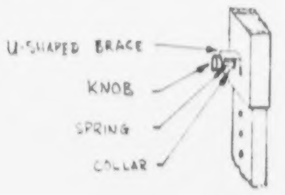
With the help of Paula Glazer and Kerry Fehr of the MacKay Center, the following design criteria were established:

1. Adjustable in height
2. Adjustable in tilt
3. Mobile in a school environment
4. Aesthetically pleasing
5. Can accommodate a wheelchair
6. Equipped with a typewriter
7. Adequate work space
8. Non-slip, easy to clean surface
9. Low cost
10. Easy to manufacture and maintain.

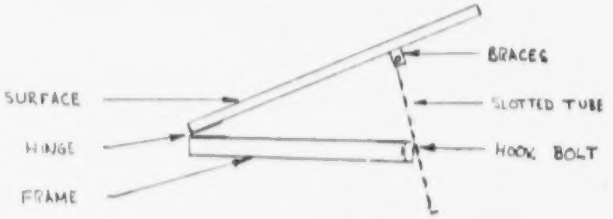
DESK DESCRIPTION

The solution to the design problem with the preceding criteria in mind, may be broken down into the following components:

A. *Height Mechanism:* The desk is adjustable in height through the use of telescoping legs that lock as a spring plunger falls into holes in the inner leg.



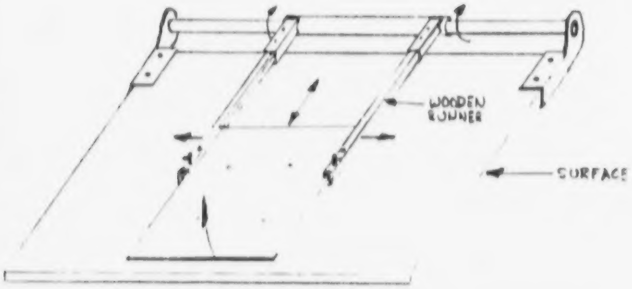
B. *Tilt Mechanism:* The tilting of the desk top is implemented by hooking a slotted, steel tube onto a bolt protruding from the back of the main frame. The tube is attached to the desktop by two L-shaped braces and the desk top is screwed to hinges welded to the frame.



C. *Wheels:* The use of lockable rubber casters permits mobility in all directions. Positioned at each corner, they provide a stable and stationary surface for writing and typing.

D. *Frame:* The frame consists of tubular 2 x 1 inch SAE 1020 steel. An effort has been made to minimize weight and cost while keeping the structure strong. The large U-shaped section is open at the front in order to allow more room for the student's legs and wheelchair. This is in turn supported by two inverted T-shaped telescoping legs onto which the wheels are bolted.

E. *Typewriter Fixture:* The electric typewriter is screwed to a lockable, aluminum plate that slides between two wooden runners. These are attached to a steel tube that can move on a fixed rod secured across the back of the desk top. The fixture may be moved laterally or longitudinally on the surface. Lifting the assembly radially upwards makes it possible to remove the typewriter from the surface so that it is easily cleaned, and can be used for other purposes.



F. *Surface and Armrest:* The surface is finished pressboard that is easily cleanable and aesthetically pleasing. A removeable 8" x 8" non-slip mat is placed on the desk top to retain reading materials when the surface is at an angle. An armrest slides out from under the desk top on a sliding mechanism.

G. *Book Shelf:* A wooden box open at the top and front, with interior dimensions of 6" x 8.5" x 11" is attached to the right side of the frame. It serves as a bookshelf and can be easily removed.

CONCLUSIONS

This adjustable desk was designed, built and tested with the help of various McGill University Mechanical Engineering professors, advisors and technicians, as well as therapists and teachers at the MacKay Center.

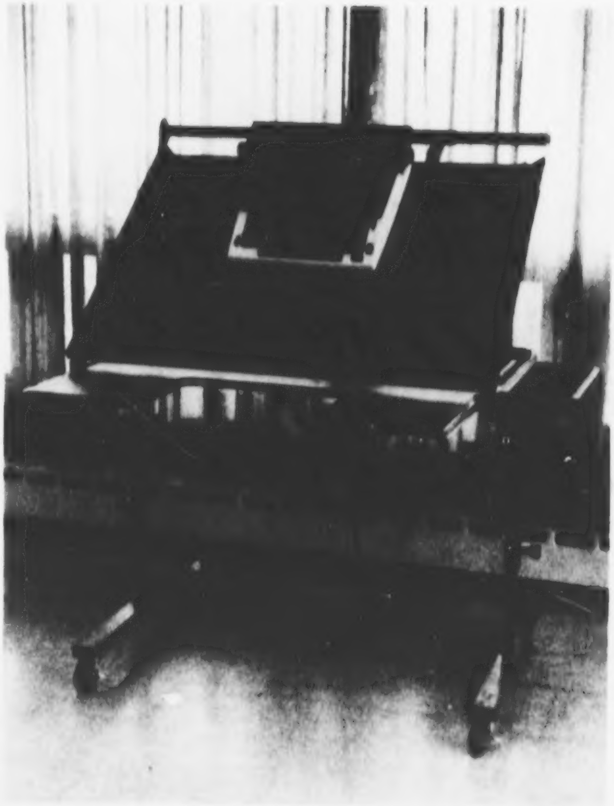
The desk was given a one week test period with students at the MacKay Center in November, 1982. The enthusiasm with which it was received and the praise it was granted was gratifying and encouraging to the McGill students involved. Staff at the MacKay Center say that the desk is better than any other available to the school. It is presently being used by a MacKay student. Fifteen to twenty desks could be purchased within the next year.

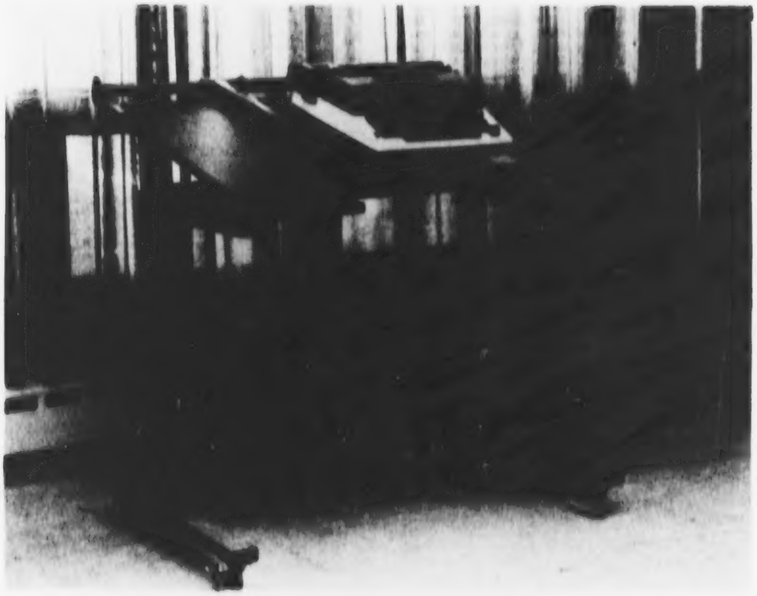
Improvements to the desk would include:

1. A larger book shelf with dividers to help the students organize their material.
2. Plastic runners for the typewriter plate in place of the present wooden ones.
3. Covering the entire surface with non-slip mat.
4. A sturdier surface
5. Bigger casters
6. Stronger height adjustment braces

Patent action has been initiated on this project. Market and manufacturing research is being conducted at Centre d'Innovation Industrielle at l'Ecole Polytechnique de Universite de Montreal. Future testing will be done at l'Ecole Victor Dore.

McGill University
Macdonald Engineering
817 Sherbrooke W.
Montreal, Quebec H3A 2K6
Canada





A BATHING AID FOR ELDERLY AND PHYSICALLY DISABLED PERSONS

Nancy J. Hurley
North Carolina State University

PROBLEM EXPLANATION

Many people, because of agine or a physical disability have difficulty in using a standard bathtub. They are not able to sit down in the tub and cannot safely step over a tub rim to enter the bath. Tubs can be equipped with seats which extend outside the tub to allow the user to first sit down, then turn and transfer his or her legs into the tub, and then slide over into the shower position. These "transfer seats" eliminate the need to step over the tub rim and make it possible for this population to safely and independently bathe.

Many households consist of both disabled and able-bodied members. Therefore, it is important that products designed for the disabled do not hinder able-bodied persons from using the bathtub in a normal manner.

PROBLEM STATEMENT

Existing "transfer seats" on the market are inadequate. Most are free-standing and therefore move or tip over; because they bridge the tub rim it is impossible to close the shower curtain, consequently water spills onto the floor; they are generally upholstered and hence wear out quickly; they require readjustment after removal from the tub; and they occupy space outside the tub often obstructing other bathroom functions.

SOLUTION

This transfer seat solves the problems of competitive designs. It is safer, more attractive, and does not limit the use of the tub by able-bodied persons. It should be noted at this time that a patent is now pending on the design. The seat consists of a molded plastic seat and transfer board, and a two part metal base. The following is a description of its features:

SECURITY - By means of a clamping mechanism connected to the transfer board, the design is clamped securely to the rim of the bathtub, preventing the seat from moving while in use.

EASY REMOVAL - A latching mechanism allows the two part base to be separated and the seat to be easily removed. The transfer board and clamping mechanism which remain on the side of the tub do not interfere with the use of the bathtub by an able-bodied person. Instead, it can be used as an accessory shelf, or a place to sit while soaking one's feet. The transfer board is unique in its design, for it cantilevers over the outside of the tub rim without the use of protruding supports, allowing a wheelchair to be pulled up to the board for easy transfer.

ADJUSTABLE TO THE NEEDS OF THE INDIVIDUAL USER - Shower seats must often be precisely located for the user's particular way of transferring. With other designs there is always much difficulty in maintaining the correct position for the seat during removal and replacement. When this seat is replaced, it snaps and locks into precisely its previous position -- no readjustment is necessary. For those who prefer to sit lower in the tub, the seat base can be connected to the clamping mechanism at five predetermined heights. This system providing both stability and height adjustment for the seat is another unique feature of the design.

Because many disabled individuals cannot sit on a hard surface, the seat is designed to be used with or without a cushion. This option is another feature which addresses the individual needs of the user.

Another need of the user is for lateral support while he or she is seated. For this reason the seat is equipped with an armrest which attaches to the base for structural support and extends above the seat along its side near the back wall of the tub.

Disabled and elderly people often need to grasp or establish a hand hold where it would not be expected of other populations. In response to this need all edges of the seat are 1-½" in thickness to provide sturdy, comfortable hand grip surfaces. For additional balance and leverage the back of the seat has an integral molded grab bar which is sized in accordance with the recommendations for grab bars of the ANSI A117.1 Specifications for Making Buildings and Facilities Accessible to and Usable by the Physically Handicapped.

ADJUSTABLE TO DIFFERENT SIZES OF BATHTUBS - The seat, with its integral back and grab bar is symmetrical and reversible. It can be removed from the metal base, rotated 180°, and remounted so that it can be used in both right and left handed tubs. The clamping mechanism clamps securely to the rim of any bathrub having a rim width of 3" to 7". And the adjustable legs allow the seat to be used in tubs ranging from 10-½" to 20" in depth. By screwing into the seat base, the legs can conform to the bottom slope of any tub providing additional stability. And clamps cushioned with waterproof foam conform to the side slope of any bathrub, increasing gripping pressure, and protecting the tub finish.

PREVENTS WATER SPILLAGE - A unique continuous curtain slot between the seat and the transfer board allows a standard shower curtain to slide through, preventing water spillage. In addition, the transfer board has a molded drip edge on its bottom inside edge which prevents water from clinging to the board and running outside the tub. It should be noted that water retainage, a very serious and dangerous problem, is not solved by competitive designs.

AN AESTHETIC APPEARANCE - Another shortcoming of competitive designs is their clinical appearance. A major design objective was to design a slim-line, but sturdy seat that would enhance rather than institutionalize its environment. Attention was given to form details such as sculpted recesses in the seat back (necessary for strength), corner radiuses, and the transition between the seat and its back which are both functional and aesthetic.

AVAILABILITY - The seat will be mass produced to minimize cost; however, due to the higher quality materials being used it will cost more than transfer seats currently available. Final production costs are now (at the time of this submittal) being estimated by the manufacturer.

DEPENDABILITY - The seat and transfer board are rotationally molded of cross-linked polyurethane for strength and durability. The glossy finish is comfortable to the skin and easy to keep clean. The adjustable base is made of polished stainless steel for a lifetime of service. The armrest is also made of stainless steel tubing and is padded with a waterproof, vinyl-coated, closed-cell foam pad. The cushion, made of the same foam material rinses clean and can easily be replaced.

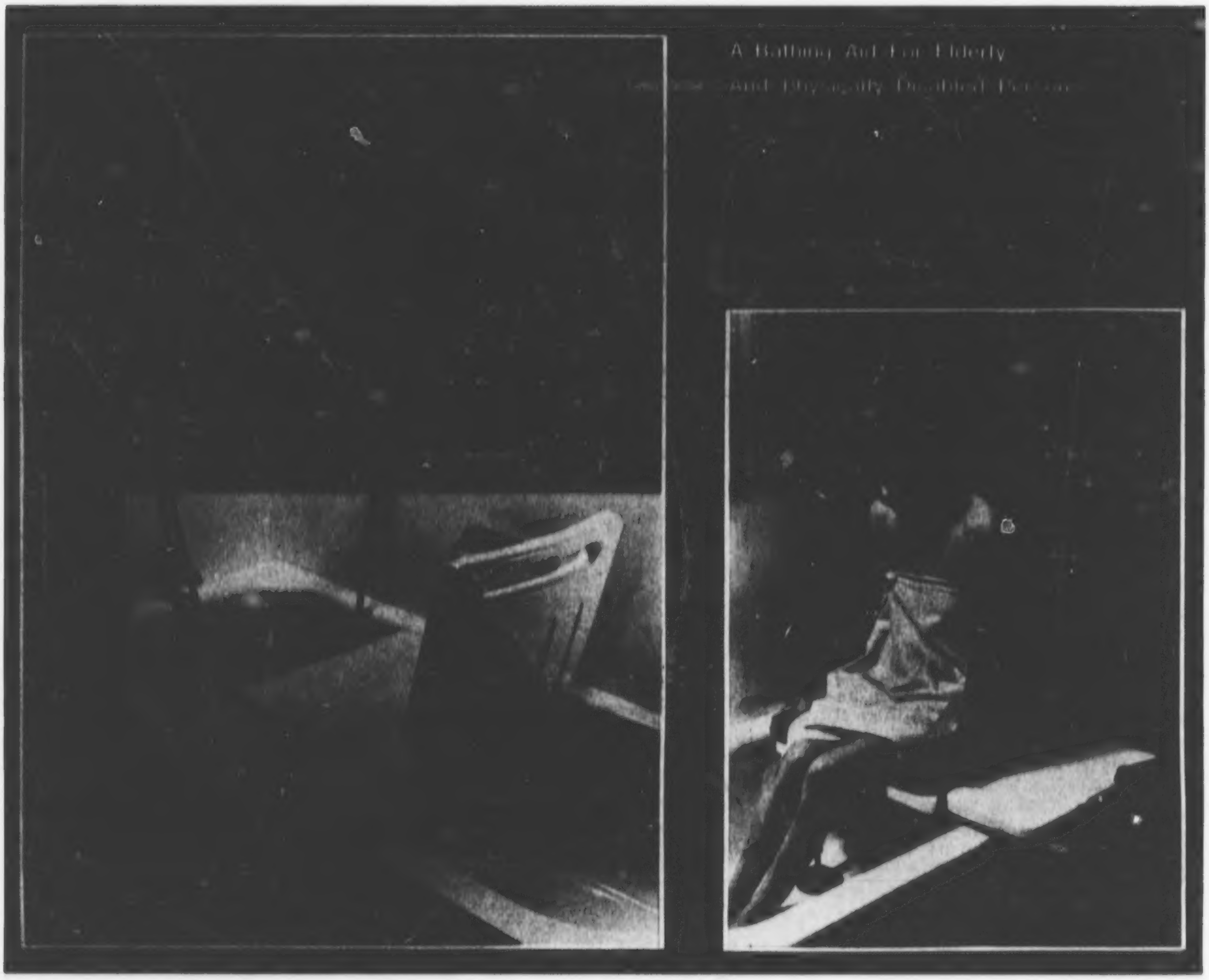
HISTORY

This design began as a studio project which was selected because of a personal interest in the design of products for people with disabilities. A recognized expert in this area, Ron Mace of Barrier Free Environments, Inc. was contacted at the beginning of the project. He defined the problem area and explained user requirements, pointing out deficiencies in existing products. Working directly with Mr. Mace, the identified problems were then addressed.

CONCLUSION

The wide range of disabilities requires products for the disabled to adapt to the individual needs and abilities of the user rather than requiring the user to adapt to the product. The design details of this transfer seat were carefully thought out and organized in order to allow the end product to be adjusted for the user as well as tailored to various environmental constraints. This design is a functional product, simple and straightforward in its use and application, which addresses the problems experienced by disabled persons as well as enhances their environment.

North Carolina State University
School of Design
P.O. Box 5398
Raleigh, NC 27650


A Bathing Aid For Elderly
Persons And Physically Disabled Persons

DESIGN OF A WHEELCHAIR SYSTEM FOR A CHILD WITH FOUR EXTREMITY REDUCTION MALFORMATIONS

Raymond Koopman

Department of Mechanical Engineering and Applied Mechanics
University of Michigan, Ann Arbor, Michigan

Introduction

The high cost and lack of availability of mobility devices often limits a person's options when purchasing a wheelchair. The limited market size discourages manufactures from developing and marketing many different mobility devices. This often means that persons with disabilities who must use a wheelchair are not able to buy a device that fully meets their needs and are therefore limited in their independence.

Custom designed systems allow a disabled person to better satisfy his/her needs. Cost and serviceability is usually a deterrent to this approach.

This paper discusses the design and construction of a custom, powered mobility system which minimizes these drawbacks. This system was built for an intelligent and lively three year-old boy who has severe reduction malformations of all four limbs. This wheelchair is a modification of another similar chair developed at the University of Michigan Rehabiliation Engineering Center to enable an adult with disability to enter a sedan type car unassisted and drive while seated in the wheelchair (1). It includes a powered seat height adjustment mechanism which permits the user to raise or lower the entire seat structure. This child can transfer into and out of the wheelchair and operate the controls without assistance. He can also access items previously unaccessible to him by adjusting the seat or moving the wheelchair. Figure 1 shows the child in the wheelchair. (Discussion of the clinical aspects for this system's prescription and delivery are presented in another paper at this meeting).

Figure 1. Child driving the wheelchair

Design Criteria

The following design criteria are incorporated into the wheelchair:

1. The seat structure has a powered seat elevator which can lower to within 4 inches or raise to 24 inches above the floor.

2. A hard seat is used which is 14 inches deep by 14 inches wide by 14 inches high. The seat is hard so as to allow easy positioning and attachment of a seating orthosis. The size of the seat allows for considerable growth.

3. The drive system is an Everest and Jennings 24 volt belt drive system with a disengage mode which allows easy manual movement of the wheelchair.

4. A footrest is not needed since the lower extremities are substantially reduced.

5. The tires are useful indoors or outdoors and are fully pneumatic. The rear tires are 10.5 inches in diameter.

6. The front wheels contain a mechanism to prevent the seat structure from lowering to the ground when the front wheels are in the way.

7. Handles are provided so that the chair can be moved manually.

8. Smooth corners and bumpers are used wherever possible to minimize damage to walls.

9. Standard parts are used whenever possible to minimize initial cost and replacement difficulties.

10. The aesthetics of the wheelchair are considered in its design.

Wheelchair Description

A wheelchair with an adjustable seat height feature was specifically designed for the child previously mentioned. When the seat is in its lowermost position the bottom of the seat is 4 inches above the ground. In this position the child can manuever himself into the chair. The dimensions of the chair were restricted to the greatest possible extent and remain within the dimensions of a standard adult wheelchair. The wheelchair consists of five major components: seat guide and elevating assembly, seat structure, chassis, drive components including the wheels, and front caster crush-prevention assembly. Figure 2 shows a schematic drawing and figure 3 an actual photograph of the wheelchair.

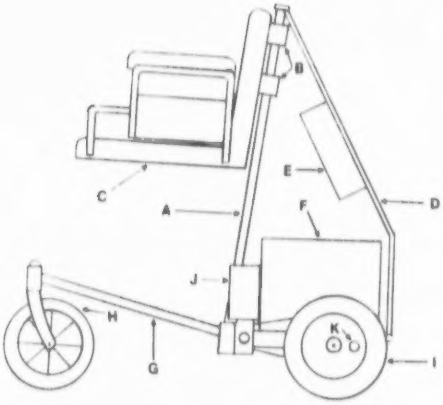


Figure 2. Schematic drawing of wheelchair with powered seat elevator.

A motion systems ball screw actuator pushes the seat along two guide rods (Fig. 1A), 3/4 inch in diameter, via four linear ball bearings (Fig. 1B). The seat frame structure (Fig. 1C) is constructed of 1/4 inch aluminum which was cut, welded and braced as necessary for rigidity. A backing plate provides a surface for mounting the linear ball bearings and for transferring the seat loads to the screw. The seat frame, both seat and backrest, are fitted with birch plywood. This provided a good surface for mounting the seating orthosis.

The two guide rods are supported at their base by the chassis cross member. Two bracing members (Fig. 1D) extend from the top of the guide rods to the back of the chassis. These members help decrease the deflection of the seat structure and of the guide rods. The wheelchair control electronics (Fig. 1E) are mounted between these members.

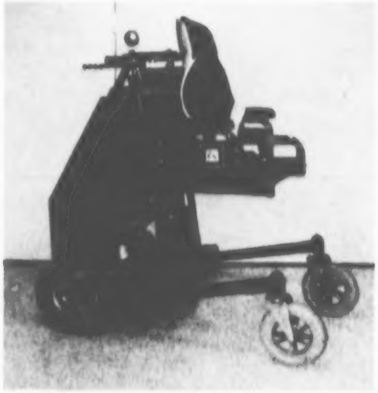


Figure 3. Powered wheelchair with seat elevator.

The battery box (Fig. 1F) and front caster tubes (Fig. 1G) are attached to the chassis cross member. The caster tubes are constructed from one inch square hollow tubing which extend perpendicularly from the edges of the cross member at a 15 degree angle from the horizontal. The seat structure lowers to 4 inches from ground level in front of the cross member and between the front caster tubes. The two caster wheels and (Davis) front forks (Fig. 1H) attach to the front of the caster tubes.

The battery box is constructed from angle iron and two 94 amp hour lead acid batteries (Donley) are used. The two 10.5 inch rear drive wheels (Fig. 1I) are located as far to the rear of the chair as possible. The wheels are connected to the Everest and Jennings motor drive motors through the use of toothed belts (Fig. 1J). The drive motors are attached to the outer edge of the cross member and means of adjusting belt tension are provided.

The Amigo company rear wheels provide a pin disengage mode (Fig. 1K) which allows the rear wheels to free wheel so that the chair can be pushed manually. The major components of the chair are all kept close to ground level for stability. Anti-roll wheels have also been added to prevent tipping.

A photocell sensor is provided within the front caster tubes to prevent the seat structure from lowering when the front casters are not aligned. A mechanical switch was considered, but was not used because: 1) a mechanical switch would have been difficult to implement considering the bearing clearances present and 2) a mechanical switch, would have a limited life expectancy.

A wood cover was designed and built to cover up the controller, batteries, and wires and enhance the appearance of the chair. The cover is hinged so as to allow easy access to the batteries for maintenance and recharging. Sharp corners are avoided and padding and bumpers are provided where needed.

Operation

The wheelchair operation begins with the seat structure in its lowest position. The child rolls or pulls himself to the wheelchair and can position himself in the seating orthosis. Once he is seated, the seat structure is raised by throwing a toggle switch mounted to the right of the wheelchair joystick. He stops the seat when he reaches the desired height and then operates the chair using a standard E&J joystick controller. The seat structure can be stopped at any height up to the maximum height of 24 inches above the floor.

Conclusion

The versatility of this chair has been shown in its initial evaluations. The maintenance of the chair is being done by a local dealer (2). The child has become proficient in the use of the chair. The chair has given this child mobility, independence, and access to many new things. The chair can be used both indoors and outdoors.

Acknowledgements

The author is indebted to Dr. Mohamed Zarrugh, Dr. Simon Levine, Mark Allen of Adaptive Wheelchairs, Inc., the technicians, and others who contributed to this design. This work was supported in part by the National Institute of Handicapped Research Grant #G008200047 and the Rehabilitation Engineering Division, Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center.

References

1. Zarrugh, M.J., Juvinall, R.C., "Design of a Wheelchair-Automobile System for the Severely Disabled Driver". Advances of Bioengineering, American Society of Mechanical Engineers, p. 59-60, 1981.

2. Adaptive Wheelchairs, Inc., 17546 Chester, Detroit, Michigan 48224.

Rehabilitation Engineering Center
208 W.E. Lay Auto Lab
University of Michigan
Ann Arbor, Michigan 48109

THE REHABILITATION SLEEP UNIT

Dalyce Laine
Cornell University
Dea/Martha Van Rensselaer Hall
Ithaca, NY 14853

The Sleep Unit is a portable, low-cost alternative to a hospital bed for people who, for medical reasons, must sleep or rest with the uppor torso area elevated. It is placed on top of any regular bed mattress, adjusts to a wide variety of elevations and can be used for a wide range of body sizes and proportions. The unit is compact to meet the needs of short term use, rental, storage and portability. It incorporates features that provide for the prevention of decubitous ulcers. It can be easily washed and sterilized.

Many individuals are required to sleep or rest in an elevated position. Some people who need torso elevation are mobile, while others are immobile and need assistance. Body elevation for long periods is needed for convalescence, respiratory problems, heart disease, or permanent conditions of the back and spine. Problems requiring short term use include sinus conditions where adequate drainage is needed, muscular distress of the lower back, and special cases such as, ear problems that require periodic elevation to prevent the infectious fluids from passing into the brain.

A special costly hospital bed can be purchased for use in the home. However, many individuals could benefit from having a lower cost unit that could be rented through organizations such as Hospicare or sick-room rental agencies connected with pharmacies. Torso elevation is not a single dimensional problem. Different degrees of elevation are required according to individual needs. In an elevated position, the torso tends to slide downward off the incline. Sheets and blankets fall down and leave the torso uncovered. The pillow also slides away. Solutions to these problems connected with torso elevation are considered in the design of the unit.

The Sleep Unit consists of six components:

1) The *ELEVATION FRAME* is secured around any mattress at the head of a bed. It has two sections that are hinged together: a triangular base and a back rest. The back rest is supported by three arms which provide varying elevations from a minimum two pillow height to a maximum elevation of 75 degrees. (fig. 1)

2) The *BACK REST COVER* is made of canvas which stretches across the back rest surface. Velcro® strips are secured to the canvas and serve as attachment points for other elements of the system.

3) The *COMFORT WEDGE (AND CASING)* is a fabric unit that extends from the top of the back rest to below the knee level on the bed and encloses a foam back rest wedge. The velvet loop backing on the comfort wedge casing adheres to the Velcro® strips on the back rest cover. The 100% cotton unit has two pockets that span its width of 36". The upper pocket is attached to the wedge area. The lower pocket is in the leg area and houses the slide control (see #4 below). Both pockets are designed to hold any one of a variety of comfort, anti-decubitous ulcer products such as egg crate foam, an air mattress or pressure relief pads. To hold the casing securely, straps are sewn to the underside of the lower pocket and are wrapped around the mattress.

4) The *SLIDE CONTROL* is made of a shaped piece of covered foam that is adjustable to fit under different knee positions. The velvet loop backing is secured to the Velcro® strips inside the lower pocket of the comfort wedge.

5) The *BACK ROLL* is used to support the lumbar and sacrum area. A folded towel is rolled with the specially designed cotton case and closes with the Velcro and velvet loop system. The roll attaches with its strap to the backing of the comfort wedge and Velcro® tabs.

6) The *SHEETING/BED JACKET SYSTEM* is a "one-size-fits-all" full length garment. It is made of a cotton knit fabric and designed to keep the shoulder and neck area warm while convalescing or sleeping. The arms slip easily through the low armhole and the system becomes a sheet. The system is held in place by the back extension that is secured with Velcro® at the top of the comfort wedge and permits adjustability for different body heights. This upper back extension includes a case in which a standard pillow can be held in place. To function as a sheet, a woven cotton extension tucks under the foot of the bed mattress. A blanket can also be tucked under the comfort wedge. (fig. 2)

The components of the Sleep Unit are removable so that they can be reassembled into a rectangular shape. The adjustable components fit into the base and the lower pocket of the comfort wedge. The unit is then ready for storage and/or transportation. (fig. 3) The handle on the base makes it easy for anyone to transport the unit.

The Rehabilitation Sleep Unit was designed to provide varying elevations, control the sliding of the body, secure the sheet and pillow, ensure adjustability to body sizes and proportions to meet the 97.5% percentile of the population, and provide compatability with existing products. The compact Sleep Unit meets the needs of rental and storage. Its cost, about one-third the cost of a special hospital bed, and its portability make it potentially available to many individuals.

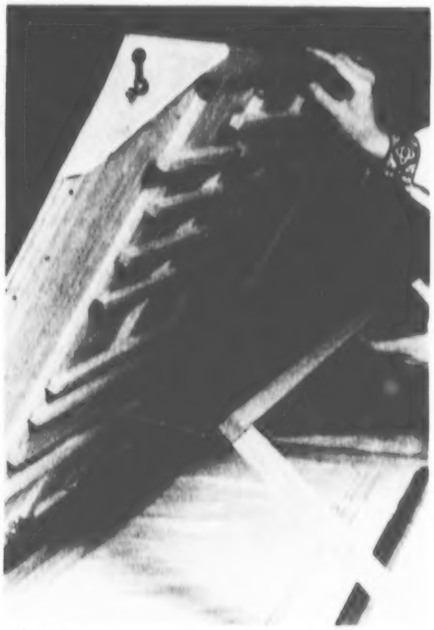


fig. 1

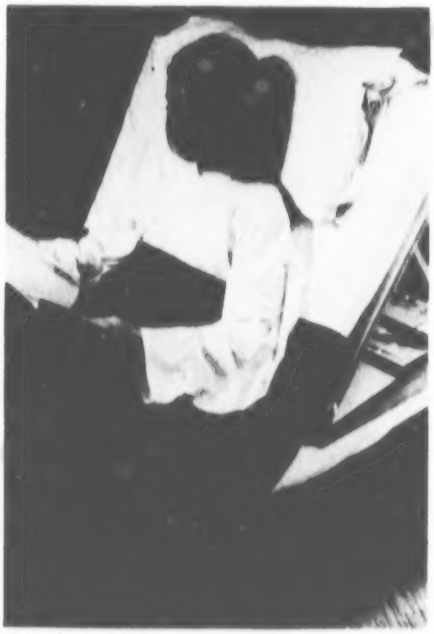


fig. 2

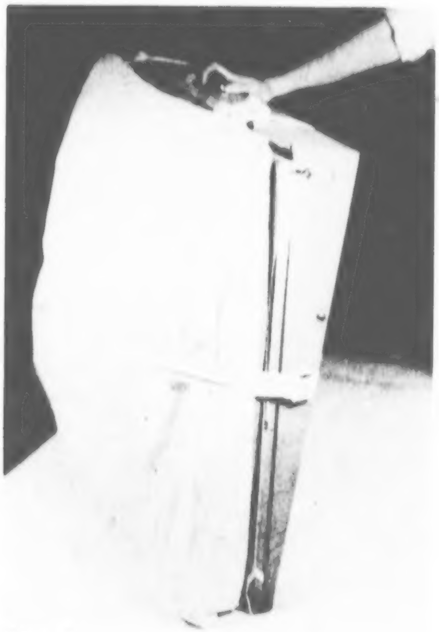


fig. 3

Continuous Passive Range of Motion Machine

Steven Reinecke, Steven Arms
University of Vermont
Department of Orthopaedics & Rehabilitation

INTRODUCTION

Continuous passive motion (CPM) has recently been shown to have many beneficial effects. In 1980, Salter et al[1] showed that CPM had greatly improved the gross and histologic appearance of full-thickness rabbit knee articular cartilage defects. In 1982, Salter et al[2] showed in rabbits that CPM, prior to activity, produced superior cartilage at the defect site, and the least degenerative changes in the joint one year after the cartilage defects were made. Immobilization prior to activity produced poor results. Thus the benefits of CPM appear to be long-lasting.

Injuries to tendons may also benefit from early mobilization. Gelberman et al[3] (1980) investigated the healing of dog flexor tendons in which lacerations were made. These authors showed that early mobilization produced stronger, stiffer and better vascularized tendons than totally or partially immobilized tendons. More recently, Gelberman et al[4] (1982) has concluded that early protected passive mobilization augments the physiologic process that determine the strength and excursion of repaired flexor tendons.

Salter and Minster[5] (1982) used the semitendinosus tendon as a replacement for the medial collateral ligament in rabbits. Immobilized, caged and CPM groups were compared. Tenodesis strength was found to be greatest for the CPM group.

O'Driscoll, et all[6] (1983) has shown in rabbits that CPM is effective in accelerating the clearance of a hemarthrosis and in decreasing the trapping of erythrocytes in the synovium. With CPM, convalescence time for patients with acute or traumatic hemarthoroses would be shortened and muscle atrophy and joint stiffness would be minimized. It is possible that prompt and complete clearance of blood from the joint and synovium might reduce the risk of late secondary arthritis.

To add to the growing list of CPM benefits, Coutts, et al[7] (1982) reported that patients who had undergone total knee arthoplasty demonstrated faster and greater knee flexion if they were rehabilitated with CPM when compared to a control group of patients immobilized in plaster. Also, the CPM patients showed a decrease in the need for pain medication.

It has been suggested that improved regeneration of articular cartilage, and improved soft tissue repair with CPM is related to enhancement of the circulation of synovial fluid.[8]

Because of the advantages of knee rahabilitation with CPM and some special design requirements, we set out to build a machine for the Medical Center Hospital of Vermont at a cost which would be appropriate for the department budget.

DESIGN CRITERIA

Initially, an investigation was carried out on CPM devices presently on the market. Advantages and criticisms were discussed with doctors and physical therapists who had previous exposure to a commercial machine. The design criteria for the device were:

1. the unit must be portable
2. easy to set up
3. inexpensive
4. adjustable for the femoral length, tibial elevation and height of knee axis of rotation
5. the plane of the tibial support must be adjustable in order to control internal and external tibial rotation
6. the machine must be variable in speed
7. power supply must be DC for safety
8. range of knee motion (ROM) must be easily adjustable
9. the hinging system at the knee joint should simulate the center of rotation of the knee to prevent unusual kinematics
10. a foot plate must allow the foot to either move freely or move in direct proportion to the movement of the knee

MATERIAL AND METHODS

The CPM was constructed out of aluminum with a 12 volt DC torque motor as the driving mechanism (Fig. 1).

The motor is placed under the unit to keep it compact with a separate control box for safety and accessibility. The motor control incorporated a high and low speed switch with a variable speed control in each of these ranges. Telescoping tubes are also used in order to elevate the tibia and to control internal and external rotation. "Range of motion adjustments" trigger a "two-sided" switch. This reverses the motor's direction, thereby controlling the range of motion of the knee. The hinging system consists of two polycentric hinges with a transverse padded bar that is adjusted so that when the leg is placed on the CPM, the hinges will be at the proper position on either side of the knee.

The knee CPM machine can operate in unison with the foot plate or the foot plate can work independently. The machine can be adjusted to any femur length and the foot plate has an adjustment so that the foot can be internally or externally roated. The foot plate has three modes to which it can be set: 1. the plate can move freely with no resistance to the ankle joint 2. the plate can be set to any predetermined angle and locked into that position, or 3. the plate can move in proportion to the CPM. The magnitude of ankle joint ROM is controlled by raising or lowering the "foot plate adjustment block" (Fig. 1). By raising the block, the angle of the foot plate will be in a locked position regardless of the angle of the knee. Lowering the block completely will cause the ankle joint to move through the maximum range of motion. When the foot adjustment block is placed at a midpoint setting, any desired range of ankle joint motion can be achieved.

RESULTS

The CPM machine was completed in July of 1982 and has been used clinically on an average of seven hours a day for nine months.

Problems with the prototype CPM occurred after the foot plate was added. The original 10 lbs. thrust stepper motor was replaced by the present torque motor. An acme threaded rod with a nut is coupled to the torque motor which acts as the drive system. The femoral support length also created a problem because of the wide variety of lengths it needed to accomodate. This problem was corrected by using a three piece telescoping rod.

CONCLUSIONS

A thorough evaluation of a new knee CP, machine was made after seven months of use. Patients on the CPM found it comfortable after the first few minutes. Physical therapists found it easy to set up and operate. The CPM machine has several advantages over other CPM's presently on the market. These include:

1. Polycentric knee joint hinges
2. Adjustable femoral support
3. Adjustable tibial support with control over internal and external tibial rotation.
4. Portability
5. Three-mode adjustable foot plate

There is no CPM machine as versatile and efficient as this one, constructed at a cost of only $1,000.00.

The benefits of CPM should be available to all patients with knee or ankle joint trauma. We hope that this device will make it possible for more trauma centers to incorporate a versatile CPM machine into their rehabilitation programs.

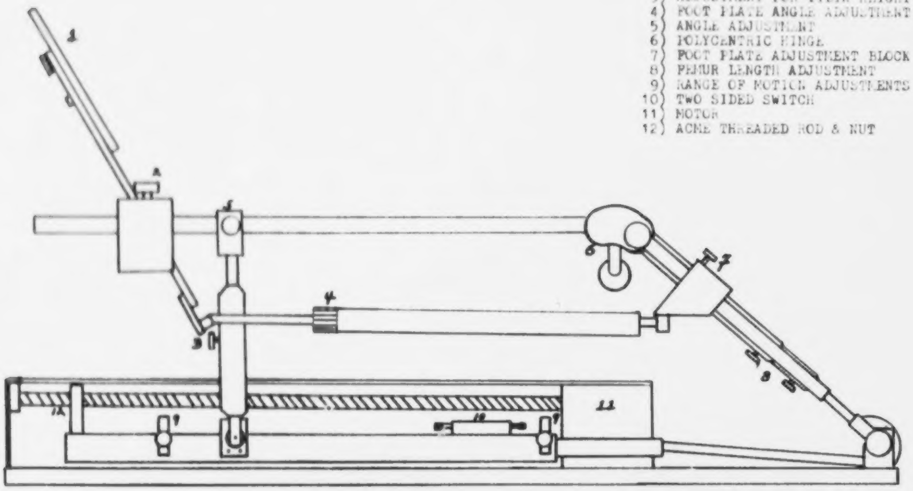
REFERENCES

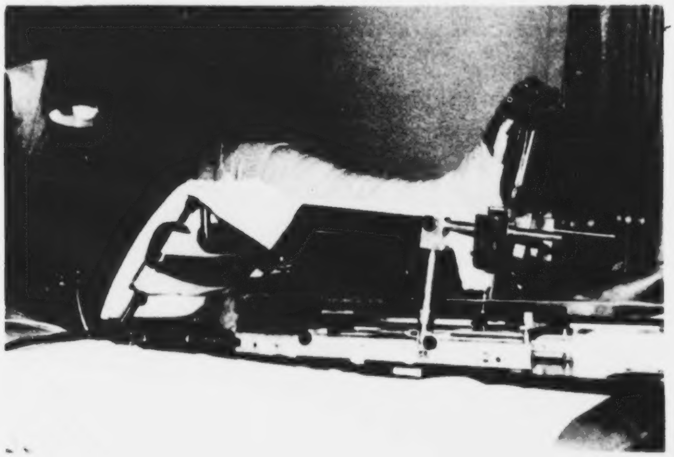
1. Salter RB, Simmonds DF, Malcolm BW, Rumble EF, Macmichael D, Clements ND: The biological effect of continuous passive motion on the healing of full-thickness defects in articular cartilage. JBJS 62(A) 1232-1251, December 1980
2. Salter RB, Minster RR, Bell RS, Wong DA, Bogoch ER: Continuous passive motion and the repair of full-thickness articular cartilage defects-a one year follow-up. 28th Annual ORS, New Orleans, Louisiana, January 12-21, 1982
3. Gelberman RH, Menon J, Gonsalves M, Akeson WH: The effect of mobilization on the vascularization of healing flexor tendons in dogs. Clin Orthop & Rel Res, N153:283-289, Nov-Dec, 1980
4. Gelberman RH, Woo S L-Y, Lothringer K, Akeson WH, Amiel D: Effects of early intermittent passive mobilization on healing canine flexor tendons. J Hand Surg V7(2): 170-175, 1982
5. Salter RB, Minster RR: The effects of continuous passive motion on a semitendinosus tenodesis in the rabbit knee. 28th Annual ORS, New Orleans, Louisiana, January 12-21, 1982
6. O'Driscoll SW, Kumar A, Salter RB: The effect of continuous passive motion on the clearance of a hemarthrosis from a synovial joint: An experimental investigation in the rabbit. 29th Annual ORS, Anaheim, California, March 8-10, 1983
7. Coutts RD, Kaita J, Bait R, Mason R, Dube R, Amiel D, Woo S L-Y, Nickel V: The role of continuous passive motion in the postoperative rehabilitation of the total knee patient. 28th Annual ORS, New Orleans, Louisiana, January 12-21, 1982
8. Ham AW: *Histology*. Ed. 7, pp. 456-458, Philadelphia, J.B. Lippincott, 1974

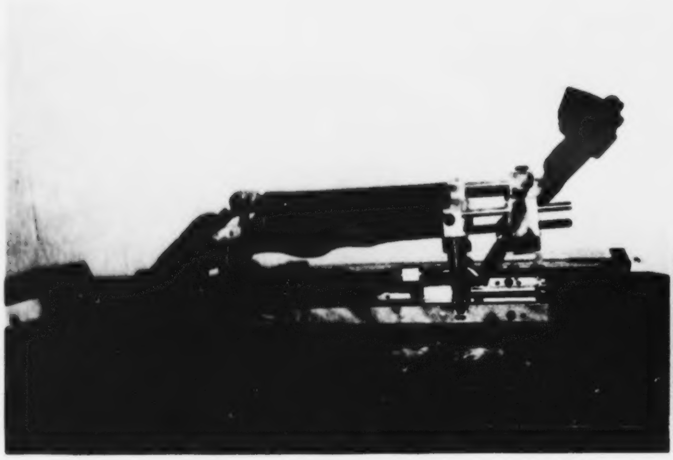
University of Vermont
Burlington, VT 05405

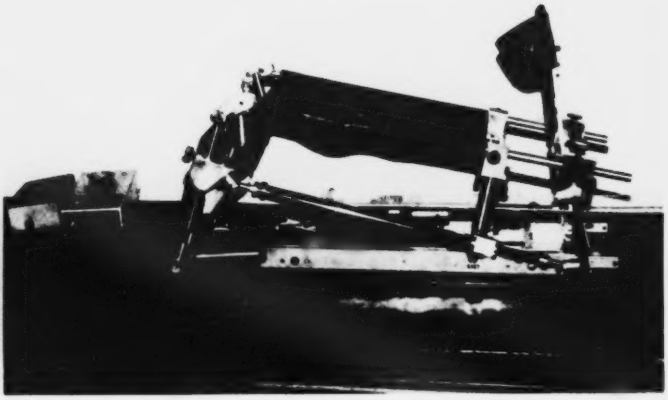
FIG #1

1) FOOT PLATE
2) FOOT PLATE ADJUSTMENT
3) ADJUSTMENT FOR TIBIA HEIGHT
4) FOOT PLATE ANGLE ADJUSTMENT
5) ANGLE ADJUSTMENT
6) POLYCENTRIC HINGE
7) FOOT PLATE ADJUSTMENT BLOCK
8) FEMUR LENGTH ADJUSTMENT
9) RANGE OF MOTION ADJUSTMENTS
10) TWO SIDED SWITCH
11) MOTOR
12) ACME THREADED ROD & NUT









A FIBER REINFORCED COMPOSITE-FOAM LAMINATE FOR LIGHTWEIGHT ORTHOSIS

Richard B. Strebinger

Rensselaer Polytechnic Institute

INTRODUCTION

Light weight, high strength, improved fit, ease of fabrication and reformability are the goals toward which orthotists, engineers and doctors have strived for in the design and prescription of orthotic devices[1,2,3]. With the development of advanced composite materials, radical improvements in orthotics and prosthetics have become feasible.

The primary advantage of these materials, where high strength fibers reinforce a plastic matrix, is that their strength and stiffness per unit weight can be up to four times greater than conventional materials such as aluminum, steel or wood. Composite materials can be oriented so as to achieve a material that is much stiffer and stronger in one direction than another. Hybrid laminates formed by combining two or more different materials can be used to obtain material properties unique to any of the single constituents. For example graphite fibers, which are rather brittle, can be combined with Kevlar fibers, which are tough but relatively weak in compression, to provide a very strong, tough hybrid laminate suited for orthotic devices. When flexural stiffness and strength are essential, a sandwich construction, composed of stiff, strong laminates bonded to either side of a light weight honeycomb or foam core, can be employed.

Previous attempts [1,4] to fabricate composite leg braces revealed two major disadvantages: the device could not be reformed after its initial construction and sophisticated fabrication techniques were necessary. A new technique has been developed which utilizes a sandwich construction, with a thermoplastic foam core. With the thermoplastic foam, the desired shape can be taken directly from the patient's body, and reformability after the laminate has been completed is possible. These characteristics combined provide not only greater load carrying capabilities but help to increase the patient's mobility[3].

THEORY

The technique was first applied to the design of a long leg brace concentrating specifically on the band/strut configuration. The basic design parameters considered for the struts were the loads resulting from the ground reaction forces at the foot during normal walking[5]. The most significant loads were an axial force directed along the strut and a bending moment due to the curvature of the legs (Fig. 1). This moment can become quite substantial should the eccentricity of the leg be large. Shear and torsional loads in the struts were neglected, being insignificant when compared to the axial loads. Theoretical calculations[6] showed that five layers of graphite, bonded to either side of a 1/4" thick, 1" wide strip of foam, were required to support an axial load of twice body weight plus the bending moment. A layer of Kevlar was added to the outer surface of the strut for impact and damage protection. The flexural stiffness-to-density ratio for the composite laminate was determined to be twice that of the conventional brace material, aluminum (Fig. 2). This is analogous to either twice the stiffness for the same weight or half the weight for an equivalent stiffness.

FABRICATION

Fabrication of the struts is quite simple and requires very little technical knowledge and no special equipment. A thermoplastic foam, (Klegecell, American Klegecell Corporation, Grapevine, Texas), which is available in various thicknesses and densities, is cut to desired lengths and widths and placed in an oven at 130°C for four minutes, adjustments can be made as required. This is possible since the core is a thermoplastic material which can be deformed upon heating. Even though the thin outer composite layers utilize a thermosetting matrix, they can be easily bent in an elastic manner when the foam core softens and they are no longer rigidly connected. It should be emphasized that a solid composite laminate would not allow such a phenomena to occur.

A similar procedure can be used for the bands. An appropriate sized piece of foam is heated and placed around the calf, thigh or knee to obtain the correct curvatures. A laminate is contructed using fiberglass cloth instead of graphite since the stresses are low and some flexibility is desired. The glass cloth is oriented at ± 45° to the limb axis to accommodate the torsional loads on the brace. The complete band/strut configuration (Fig. 4) has a total weight of 8½ oz., a weight savings of 66% over the metal counterparts.

Simple modifications to the struts have allowed two different types of knee joints to be used with composite struts (Fig. 5). One method replaced the foam near the knee with plywood or high density foam to provide a very rigid laminate that can be drilled and bolted to ensure positive fastening of a knee joint. Another method involved tapering the ends of a metal joint to form tabs which are then inserted into the ends of the struts. These ends are then wrapped in fiberglass to fix the knee joint in place. Direct mounting of lightweight bushings in the composite laminates is also under investigation.

DISCUSSION

The success and convenience of the technique described above are due to the combination of the high performance fibrous composite with the thermoplastic foam core. This technique has the following advantages.

Firstly, it eliminates the need for plaster molds in most instances. Although the plaster casts have the advantage that they can be modified to reduce pressure on bony protuberances, the foam can be locally modified with a heat gun to obtain similar results. Secondly, it allows for limited reformability after the laminate has cured. Previous fabrication processes using epoxy resin preimpregnated composites usually require high temperature and pressure for curing. This is not only an expensive operation but the finished product, a solid laminate, does not lend itself to reforming. Sandwich constructions, utilizing the foam core and room temperature curing resings, can be easily fabricated and allow for adjustments to be made with the finished product.

For reasons of material availability, the device shown in Fig. 4 was constructed using an epoxy resin. This is obviously not the most biocompatible choice. Polyester or acrylic resings could be substituted with only slight losses in mechanical properties.

Increased commercial use of composite materials has significantly reduced the cost of these materials over the past few years. Graphite cloth used in this project costs $35.00 per square yard. One square yard will accommodate five struts, that is, two and one-half braces and the cost of the foam and fiberglass is insignificant. Material costs should not be a significant impediment to the adoption of this technology. Furthermore, fabrication costs are potentially lower than for conventional metal/plastic devices and the only equipment required is a low temperature oven and a vacuum pump.

CONCLUSIONS

Since physically handicapped persons are functionally weak, ultra lightweight but strong devices would greatly increase patient mobility and quality of life.

Composite foam sandwich construction offers a feasible alternative to conventional methods of prosthesis or orthosis fabrication. Devices fabricated using this technique will have the following advantages: 1) Greatly increased strength per unit weight; 2) Easier methods of fabrication, including the possibility of forming directly on the patient's body and limited reforming of the finished device; 3) Modest cost.

ACKNOWLEDGEMENTS

The author would like to thank Professor Cecil G. Armstrong for his guidance and consultation throughout this project and Mr. Volker Paedelt for his addistance and use of the Composites Laboratory.

REFERENCES

1. McFarland, S. R. and G. Grimes; "Application of Lightweight Composite Materials to Use in Artificial Limbs and Limb Braces"; Final Technical Report. SwRI Project 13-9112; Southwest Research Institute; April, 1976.
2. Staros, A.; "Materials Problems in Prosthetics and Orthotics Design and Development"; *Bulletin of Prosthetic Research;* Fall, 1969, pp. 201-204.
3. Lehneis, H. R.; "New Developments in Lower-Limb Orthotics Through Bio-Engineering"; *Archives of Physical Medicine and Rehabilitation;* July, 1972, pp. 303-310.
4. Johnson, G.R.; "Carbon and Glass Fibre Laminates as Possible Materials for the Contruction of Body Support Systems"; Paper C233/77, I. Mech. E., 1977.
5. Yamashita, T. and R. Katoh, "Moving Pattern of Point of Application of Vertical Resultant Force During Level Walking"; *Journal of Biomechanics;* 1976, Vol. 9, pp. 93-99.
6. Tsai, S. N. and H. T. Hahn; *Introduction to Composite Materials,* Technomic Publishing Company, Westport, CT 1980.

Rensselaer Polytechnic Institute
Jonsson Engineering Center
Troy, NY 12181

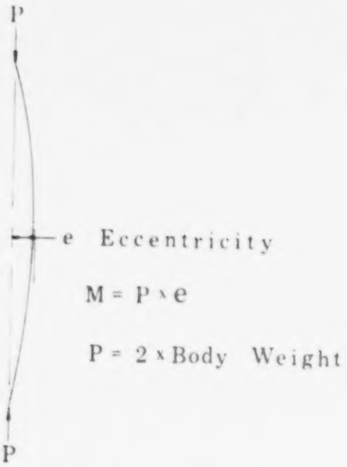

P
e Eccentricity
M = P x e
P = 2 x Body Weight
P

Fig. 1. Resultant Loads Acting on Strut

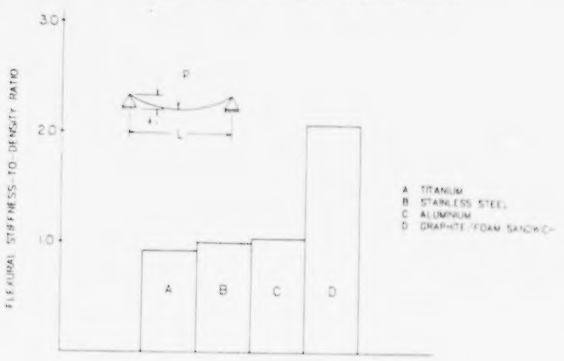


Fig. 2. Graph of Flexural Stiffness-to-Density Ratios for Various Materials

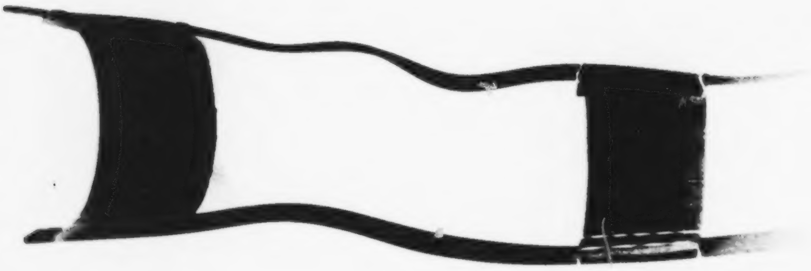


Fig. 3. Band/Strut Configuration Showing Foam Contours of the Right Leg

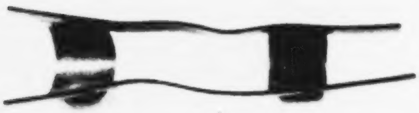


Fig. 4. Completed Band/Strut Configuration Using Sandwich Construction, Right Leg

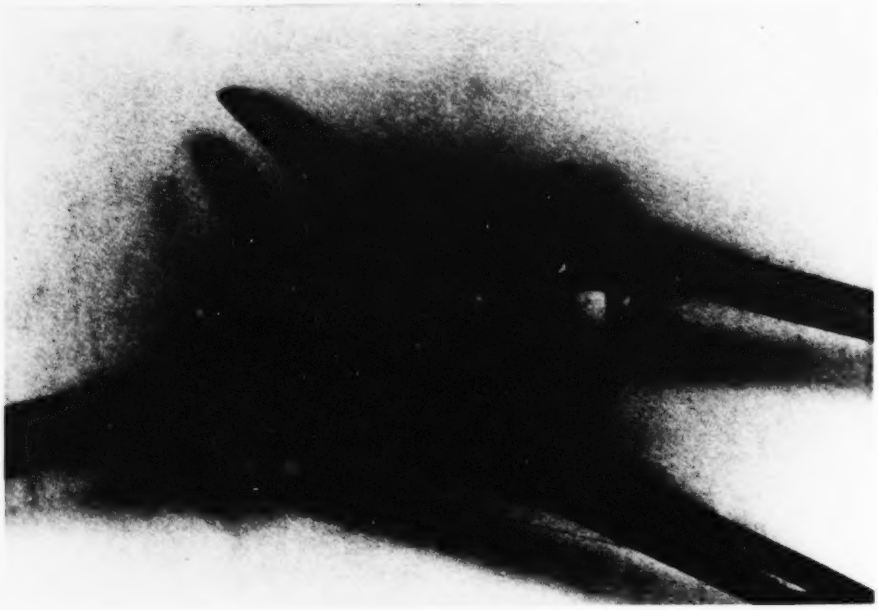


Fig. 5. Two Methods of Attaching Metal Knee Joints to the Composite Struts

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